A PENTON PUBLICATION
FEBRUARY 2004
THE HIGH SPEED ELECTRONICS GROUP

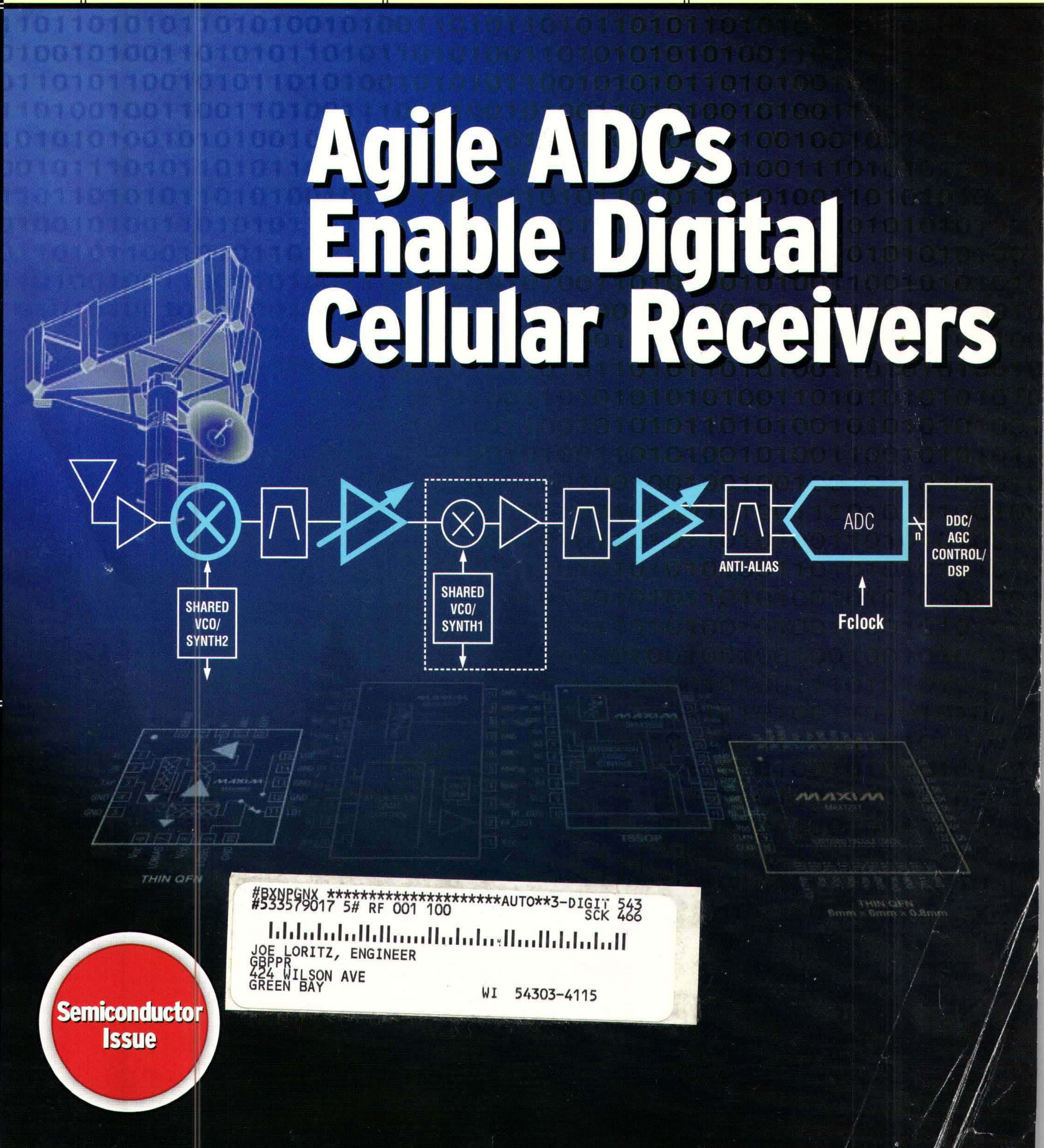
Microwaves & RF

News
Process enhancements advance semiconductors

Design Feature
Assess multicarrier cellular direct-conversion transmitters

Product Technology
Gain blocks take aim at improved reliability

Agile ADCs Enable Digital Cellular Receivers



Semiconductor Issue

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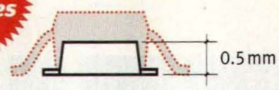
New NEC Bipolar Transistors

Higher f_Ts, Lower 1/f

New, Smaller Packages

Wireless Systems Design Conference • BOOTH 513 • Mar 8–10

NEW Packages



- **Flat Lead** design reduces parasitics and improves electrical performance
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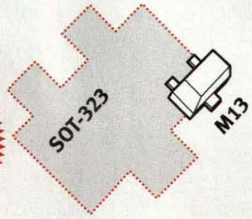
With the best *1/f* performance available, these devices help you achieve the phase noise your design demands. They're also available in Twin Transistors.

Part Number	Corner Freq*	V_{CE}	I_C	Package
NE851M13	1 KHz	1 V	5 mA	**M13**
NE894M13	3 KHz	1 V	5 mA	**M13**
NE685M13	5 KHz	3 V	5 mA	**M13**

**Review Application Note AN1026 on our website for more information on 1/f noise characteristics and corner frequency calculation.*

1/6 SIZE



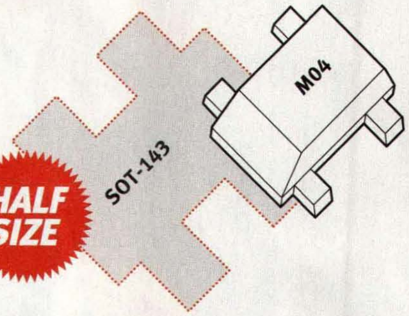
M13 One sixth the footprint a SOT-323

LNAs

Need low noise and high gain in an ultraminiature package for your hand-held wireless products? These new high frequency NPN transistors deliver!

Part Number	Description	NF	Gain	Freq	Package
NESG2021M05	35 GHz f_T LNA	1.3 dB	11 dB	5.2 GHz	**M05**
NE662M04	23 GHz f_T LNA	1.1 dB	16 dB	2 GHz	**M04**
NE687M13	14 GHz f_T LNA	1.4 dB	14 dB	1 GHz	**M13**

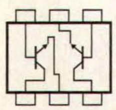
HALF SIZE



M04/M05 Half the footprint of a SOT-143

Twin Transistor Devices

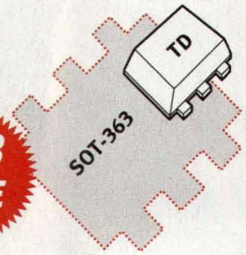
Cascode LNAs, cascade LNAs and oscillator/buffer combinations are just three possible uses of these versatile devices. *Matched Die* versions pair two adjacent die from the wafer to help simplify your design, while *Mixed Die* versions — an NEC exclusive — let you optimize oscillator performance while achieving the buffer amp output power you need. Many combinations are available.



One of three pin-outs available

Part Number	Description	Q1 Spec	Q2 Spec
UPA802TC	Matched Die/Cascade LNA	NE681	NE681
UPA895TD	Matched Die/Dual Oscillator	NE851	NE851
UPA861TD	Mixed Die/Osc-Buffer Amp	NE687	NE894
UPA862TD	Mixed Die/Osc-Buffer Amp	NE685	NE851

1/3 SIZE



TD Twin Transistors

Less than one third the footprint of a SOT-363.

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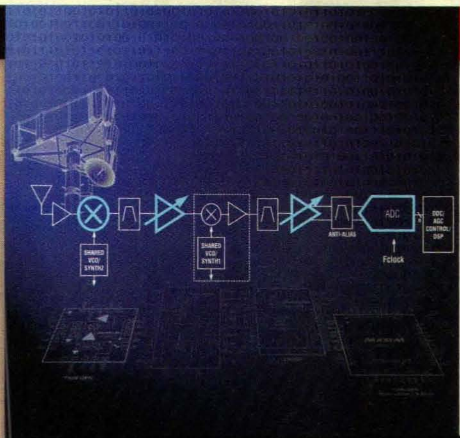

COVER STORY

News

Design

Product Technology

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The challenges of military engagement, data transmission and wireless communication require solutions that work. K&L Microwave understands the demands of the real world and has long been a leader in defining the standard for microwave and filter technology. Our focus of Innovation in Motion is to continue to move technology beyond the possibilities and into the field. Every day, mission critical information is delivered point-to-point and around the globe through the superior performance of our technology.

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- Integrated VCOs and associated loop filters
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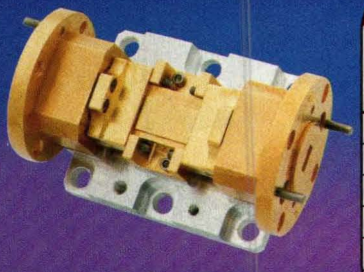
MILLIMETER WAVE COMPONENTS

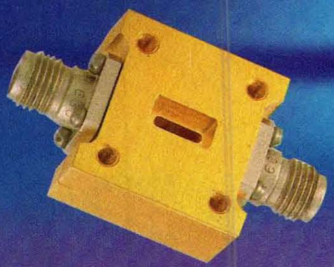
AMPLIFIERS • MIXERS • MULTIPLIERS



AMPLIFIERS

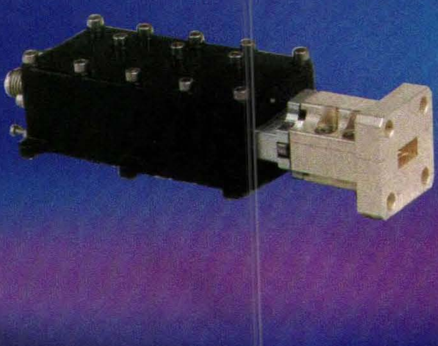
Model Number	Frequency (GHz)	Gain (dB, Min.)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	In/Out VSWR (Max.)	Output Power at 1dB Comp. (dBm, Typ.)
JSW4-18002600-20-5A	18-26	34	1.5	2.0	2.0:1/2.0:1	5
JSW4-26004000-28-5A	26-40	25	2.5	2.8	2.2:1/2.0:1	5
JSW4-18004000-35-5A	18-40	21	2.5	3.5	2.5:1/2.5:1	5
JSW4-30005000-45-5A	30-50	21	2.5	4.5	2.5:1/2.5:1	5
JSW4-40006000-55-0A	40-60	16	2.5	5.5	2.5:1/2.5:1	0

Higher output power options available



MIXER/CONVERTER PRODUCTS

Model Number	Frequency (GHz)			Conversion Gain/Loss (dB, Typ.)	Noise Figure (dB, Typ.)	Image Rejection (dB, Typ.)	LO-RF Isolation (dB, Typ.)
	RF	LO	IF				
LNB-1826-30	18-26	Internal	2-10	42	2.5	20	45
LNB-2640-40	26-40	Internal	2-16	42	3.5	20	45
ARE3436LC1	34-36	15.5-16.5	2.7-3.3	25	4	20	60
SBW3337LG2	33-37	33-37	DC-4	-7.5	8	N/A	25
TB0440LW1	4-40	4-42	.5-20	-10	10.5	N/A	20
DB0440LW1	4-40	4-40	DC-2	-9	9.5	N/A	25
SBE0440LW1	4-40	2-20	DC-1.5	-10	10.5	N/A	20



MULTIPLIERS

Model Number	Frequency (GHz)		Input Level (dBm, Min.)	Output Power (dBm, Min.)	Fundamental Feed Through Level (dBc, Min.)	DC current @+15VDC (mA, Nom.)
	Input	Output				
MAX2M260400	13-20	26-40	10	10	18	160
MAX2M200380	10-19	20-38	10	10	18	200
MAX2M300500	15-25	30-50	10	10	18	160
MAX4M400480	10-12	40-48	10	10	18	250
MAX3M300300	10	30	10	10	60	160
MAX2M360500	18-25	36-50	10	10	18	160
MAX2M200400	10-20	20-40	10	10	18	160
TD0040LA2	2-20	4-40	10	-3	30	N/A

Higher output power options available

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UNB Article Questioned

▶▶I WAS, I admit, taken in a bit at first by the article on ultra-narrowband modulation in the December 2003 issue of *Microwaves & RF* ("Understanding Ultra Narrowband Modulation," p. 53, by Harold R. Walker). It was probably the fact that it appeared in a magazine of some quality. I should have known to put my skeptic's hat on first. I should have recalled that this same dubious idea has appeared in an IEEE journal much to their later chagrin.

I'm sorry for your magazine's sake that such an article has been published. Not only are there numerous notational errors and logical errors, there is a blatant contradiction of Shannon's law. There is little rigor and less experimental evidence to support the author's claims—claims which have been well disputed and, in my opinion, squashed by others.

I would urge you to do a little more research on the subject of VMSK and other similar modulation schemes and make the results known to your readers. As a start, the following publication may be of help:
http://www-ec.njit.edu/~haimovic/publication/BaranskiHaimovich01.pdf

And the following discussion on slashdot may be of interest:
http://slashdot.org/article.pl?sid=00/10/11/0139210

Steven Knudsen, Ph.D., P.Eng.
Research Engineer
General Dynamics Canada

Harold R. Walker's response to Steven Knudsen's letter: *It's that time again. The critics come out from all over. The problem with all the critics that I know about is they have not dug deeply enough to see what's behind VMSK. In general, they make an incorrect analysis and start their tirades. Please, they should read the files on VMSK.org.*

VMSK was demonstrated at the IEEE Consumer Communications Networking Conference in Las Vegas last month. It will be demonstrated again at The Wireless Systems Design Symposium in San Diego next month, and at the IEEE Sarnoff Symposium in April. Critics are invited to attend. They might even visit our laboratory in New Jersey.

It is far too late to claim that it doesn't work. There are student boards at three universities. Dr. John Pliatsikas obtained his Ph.D. in February 2003 with a thesis based on VMSK. Photron Sciences sponsors a graduate student laboratory at SE University, Nanjing, headed by Dr. Wu, with Dr. Wang assisting. Other laboratory sponsors at SE are MicroChips and TI. The TI group is collaborating on the filter designs. Bell South tested the method in 2000.

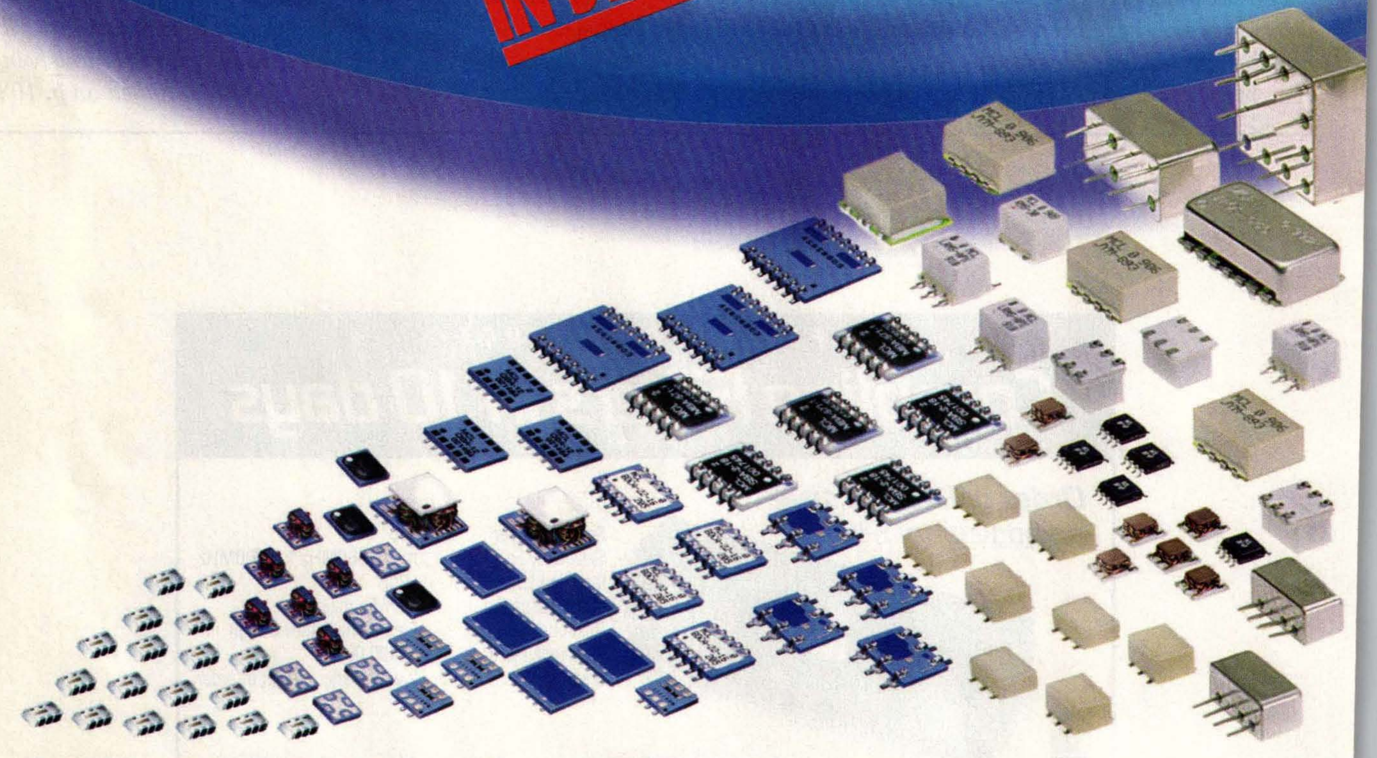
The method has been satisfactorily used on microwaves, and is now being

(continued on p. 108)

THE WORLD'S LARGEST SELECTION

POWER SPLITTERS/ COMBINERS

IN STOCK



2kHz to 12.6GHz *from* 79¢

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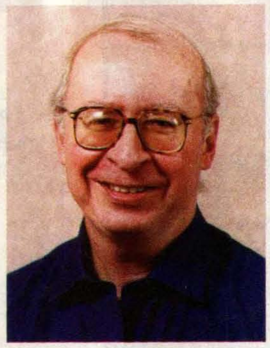
Logging Advances In Semiconductors



SEMICONDUCTOR SUPPLIERS have been active during the last few years, trying to keep pace with existing and emerging standards and trends in wireless electronics. In the history of the microwave industry, there has never been a time when specifiers have had more choices in semiconductor processes and types, from traditional silicon to high-speed/low-noise silicon germanium (SiGe) and even new gallium-based materials such as gallium nitride (GaN). Can so many choices possibly be bad?

Fewer external components translate into lower manufacturing costs for the end user and generally higher reliability for the resulting circuit.

Of course, with so much diversity comes the task of sorting through the possible options and understanding the differences in technologies. Many semiconductor suppliers offer chip sets (with transceivers, transmit amplifiers, and baseband controllers) for wireless-local-area-network (WLAN) applications at 2.4 and 5 GHz. In general, the small-signal and digital chips are based on silicon processes (such as CMOS), while the amplifiers are usually built on GaAs (for its superior electron mobility and high efficiency). Since these devices are designed to conform to various WLAN standards, such as IEEE 802.11a, b, and g, they provide similar RF performance levels, although their DC characteristics, including power consumption and bias requirements, may vary widely. When investigating active devices for a given standard, be it Bluetooth, a variant of PCS/CDMA, GSM, or WLAN, specifiers must delve deep into a data sheet for a meaningful comparison. Of course, one fairly simple way to compare different semiconductors is by their required bill of materials (BOM) for a given application—how many additional circuit elements, such as RF chokes and bypass capacitors, are needed along with the chip set. Although not always true, usually simpler is better; fewer external components translate into lower manufacturing costs for the end user and generally higher reliability for the resulting circuit.

Apologies to any RF semiconductor suppliers omitted from our survey (p. 33), and special thanks to Editorial Assistant, Dawn Prior, for her research efforts in assembling the list of RF/microwave semiconductor companies. Although many names will be familiar to RF engineers, keep an eye on some of the newer firms, such as Centellax (www.centellax.com, Santa Rosa, CA) and Nitronix Corp. (www.nitronix.com, Raleigh, NC) for future developments in two very promising technologies: SiGe and GaN, respectively.

Jack Browne

Publisher/Editor

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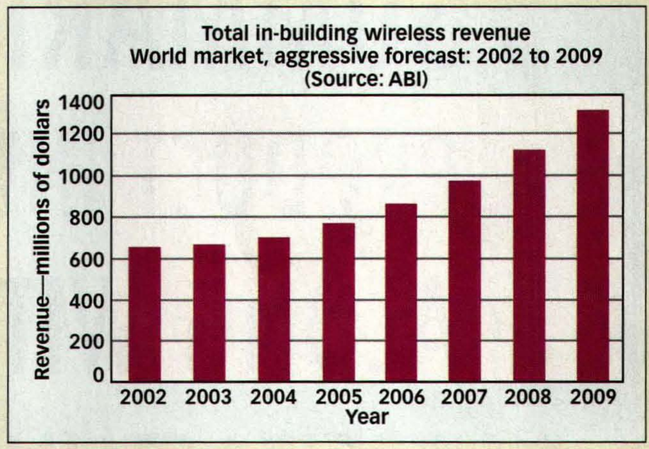
Spending On In-Building Wireless Networks Is Expected To Rise

OYSTER BAY, NY—Tough competition and the battle for network supremacy are two drivers that will push the market for in-building cellular networks north of $1 billion by the end of this decade **(see figure)**, according to a study, "In-Building Wireless Networks: Extending Cellular Networks through Picocells, Active, Passive, and Hybrid Deployments," by research firm ABI. However, limiting further growth in this market are two other factors, perhaps equally as strong: operator control and deployment costs. The most cost-efficient in-building wireless networks sometimes require an operator to give up control of the infrastructure, in a so-called "neutral-host" model.



Wireless carriers initially balked at the early demands of neutral host providers and began to consider alternative solutions by deploying their own in-building networks. High deployment costs—primarily labor costs—have made the decision to deploy carrier-owned in-building networks a hard sell. Further complicating matters was the difficulty in calculating the operators' return on investment after deployment. Recently, however, success for the neutral host model has lured operators back to this thinking, as exemplified by InnerWireless' deployment within New York's Rockefeller Center Concourse.

ABI's study presents forecasts for equipment and labor markets, segmented by active and passive systems, and by region and building size.

Silicon Wave's Terry Bourk Is Selected As BARB Chairman

SAN DIEGO, CA—Silicon Wave, a supplier of integrated circuits (ICs) for wireless personal area networks, announced that their senior director of advanced products, Terry Bourk, has been selected to serve as chairman of the Bluetooth® Architectural Review Board (BARB). Dr. Bourk becomes the first chairman from an Associate member company of the Bluetooth SIG. Previously, the position of chairman has been reserved for one of the eight Promoter companies who were original founders of the Bluetooth Special Interest Group (SIG). As chairman of the BARB, Dr. Bourk will lead the committee that, in collaboration with the forthcoming Roadmap Committee, will develop the future direction of Bluetooth technology. In this effort, the BARB will focus on the architectural aspects of the enhancement proposal, including how Bluetooth specifications are created and implemented.

"I am honored to be elected to serve as the chairman of the BARB," comments Dr. Bourk. "Bluetooth technology is a mature, robust wireless standard and is quickly being integrated into a growing number of consumer and industrial products today. The recent release of the Bluetooth 1.2 core specification has provided some key improvements to the reliability and usability of products enabled with Bluetooth wireless technology. However, there is still much to be done as we look to enhance the capability of Bluetooth technology with higher data rates, improved connectability, and access schemes and a quality of service that will ensure a better user experience in multi-use scenarios."

> "Mass volume shipments will only start to build when OEMs are able to deliver products based on single chips."

New YIG Company Opens For Business In Santa Rosa

SANTA ROSA, CA—A new microwave component and subsystem company, VIDA Products, Inc., has been formed to concentrate on military and commercial applications for high Q, broadly tunable filters, oscillators, and frequency synthesizers. The company's products will utilize the unique performance advantages of YIG technology, which are further enhanced by new developments recently introduced by VIDA. These developments include extended temperature-range performance, insensitivity to vibration, very low drive power requirements, and the use of Thin Film YIG (TFY) resonators, all of which lead to cost-effective solutions to critical system needs.

Key applications include satellite and terrestrial communication systems and ELINT and ECM equipment where broad tunability, high data rate, and/or operationally secure performance are critical requirements.

In addition to the design and manufacture of products to fill both existing and new sockets, VIDA has established a fast-turnaround team devoted to the repair and upgrading of YIG-based Synthesizer products manufactured in the past by other suppliers such as VertiCom.

VIDA's principal founders are Ron Parrott, Dave Terry, and Hal Tenney, all of whom have extensive microwave industry experience at companies such as Avantek, YIG-TEK, Micro Source, M/A-COM, Teledyne MEC, and Western Microwave.

Additional corporate and product information is available at the company's website at www.vidaproducts.com.

2004 Is Shaping Up To Be A Critical Design Year For OEMs

CAMBRIDGE, ENGLAND—The low cost and power attributes of the ZigBee radio standard will vastly increase the wireless market, and 2004 will be the critical design-in year, according to predictions from Cambridge Consultants Ltd. (CCL). Home and industrial automation applications in particular will benefit, and pioneering ZigBee-enabled products should start to appear before the year's end.

However, CCL expects design trends to follow a similar path to the Bluetooth market, which only started to take off with the arrival of single chip solutions integrating both the radio and the application-specific control functions. The conditions are now right for this silicon design phase using ZigBee, but industry leaders must initiate design cycles soon if they want products on the shelf for the critical high-growth market phases starting in 2005.

"Mass volume shipments will only start to build when OEMs are able to deliver products based on single chips," says Nick Horne, manager of CCL's Radio Communications Products business unit. "The system-on-chip approach allows complete ZigBee nodes to be built for around two dollars—a fraction of competing radio technologies—and a cost threshold that will radically change product design concepts."

Wavesat And Atmel Join Forces To Lead The 802.16 Market

SAN JOSE, CA—Wavesat, Inc., a developer of orthogonal-frequency-division-multiplexing (OFDM) Broadband Wireless Access (BWA) modem silicon, announced that they have chosen Atmel's SiliconCITY capability to design and manufacture the first WiMAX-compliant IEEE-802.16d chips. Wavesat has been working this new OFDM modem technology since 1997, and this new chip represents their sixth generation of OFDM modem. Already, more than a dozen system makers are using Wavesat's development kits to design next-generation BWA systems.

"The decision to team up with Atmel further reinforces Wavesat's position as the premier provider of 802.16d-compliant chips in the marketplace," states Michel Guay, president and CEO of Wavesat. "For our customers, this alliance means that they are getting the best of OFDM wireless technology built by a world-class semiconductor manufacturer."

"Atmel is pleased to work with the worldwide leader of 802.16d/WiMAX OFDM technology," comments Jay Johnson, marketing director for Atmel. "Using our 0.18-micron SiliconCity mixed-signal standard cell library for this complex design will offer Wavesat and its customers a high-performance and cost-effective solution."

Wavesat and Atmel will have the DM256 chip available in Q2 2004. Using development kits now will enable system manufacturers to offer WiMAX-compliant systems as early as Q3 2004.

Broadband Proves Its Value In Many Different Venues

BOSTON, MA—Municipalities, schools, and hospitals have realized significant benefits from access to global information. Broadband proves valuable in areas such as homeland security, distance learning, and telehealth. However, a report from the Yankee Group entitled, *Municipalities, Schools and Hospitals Reap Broadband's Benefits*, finds that many areas still have poor access to information infrastructure and broadband services.

"The emergence of the Internet can help narrow the information gap between rich and poor, and urban and rural areas. The public sector's growing interest in broadband communications is driven by a desire to make information available everywhere," comments Lindsay Scroth, Yankee Group Broadband Access Technologies analyst. "The public sector buys most of its telecommunications services from incumbents, but must look for cheaper and broader alternatives, such as satellite, broadband wireless, and fiber."

"The emergence of the Internet can help narrow the information gap between rich and poor, and urban and rural areas."

Recognizing that Internet access can deliver economic, educational, and security advantages, municipalities continue trying to make broadband available to local areas. Despite private-sector opposition, local governments continue searching for ways to bring broadband to all businesses, homes, and government-owned facilities.

During the past five years, broadband communications has become critical to education. The US Department of Education reported in 2001 that 99 percent of public schools had Internet access. Whether used for online classes, Internet-based homework assignments, global research, or distance learning, most schools use the Internet to improve fundamental programs.

Kudos

EL SEGUNDO, CA—Applied Wave Research, Inc. (AWR), a provider of high-frequency electronic-design-automation (EDA) tools, announced that it has finalized an agreement with the Australia Telescope National Facility (ATNF) Engineering Development Group to provide EDA solutions to be used for RF, microwave, and millimeter-wave design. ATNF will use AWR's Microwave Office™ software for designing state-of-the-art cryogenically cooled receivers and associated components.

GOWANDA, NY—Gowanda Electronics is pleased to announce that it has successfully completed the transition to the requirements of ISO9001:2000 Quality Management System Standard. Preparation for the transition at Gowanda began last year. The audit was performed by NSF International Strategic Registrations Ltd. (NSF-ISR).

GRANVILLE, NY—Saint-Gobain Performance Plastics' Granville, NY facility has achieved certification under the ISO 14001 Environmental Standard. The plant manufactures a line of polymer-based foam sealing, bonding, and gasketing products.

The award was gained in an audit that also granted the company an "upgrade" to the process-based ISO9001:2000, and renewed its accreditation as a QS9000 company. The newer ISO14001 standard examines all environmental aspects and impacts of the company's business processes. On a worldwide basis, achieving ISO 14001 gives the Granville facility credibility as an environmentally responsible corporate citizen.

MEXICO CITY, MEXICO—Skyworks Solutions, Inc., a wireless semiconductor company focused on RF and complete cellular system solutions for mobile-communications applications, announced that the company has received Mexico's prestigious National Export Award in the maquiladora category. The award, which recognizes Skyworks' best-in-class module manufacturing and test facility in Mexicali, was presented to the company by Mexican President Vicente Fox in a ceremony held recently at Los Pinos, the presidential residence in Mexico City.

The National Export Award has been given annually since 1993 by Mexico's Secretariat of Commerce and Industry.

IRVINE, CA—TDK Semiconductor Corp., which is involved in the field of mixed-signal and analog communication semiconductors, has achieved ISO 14001 certification after an extensive audit by Underwriters Laboratories, Inc. (UL).

TDK Semiconductor began the ISO 14001 system implementation in early 2003. Following UL's site examination of documented procedures and operations at the Irvine, CA facility, TDK Semiconductor was awarded ISO 14001 Certification on January 8, 2004 (UL Registration File Number A12197). To ensure continued compliance with ISO 14001, UL will conduct periodic surveillance audits of the company's environmental management system and operations. MRF

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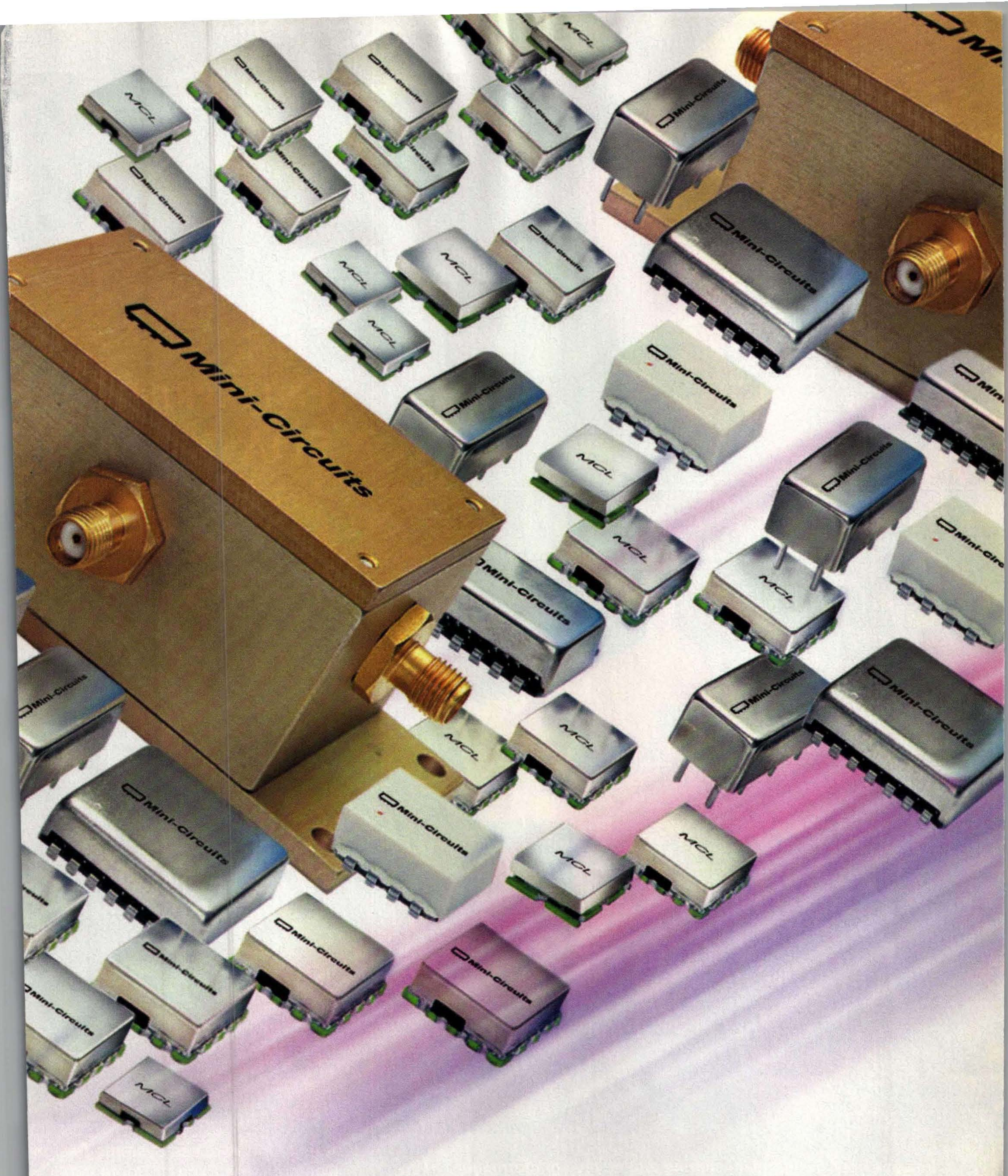
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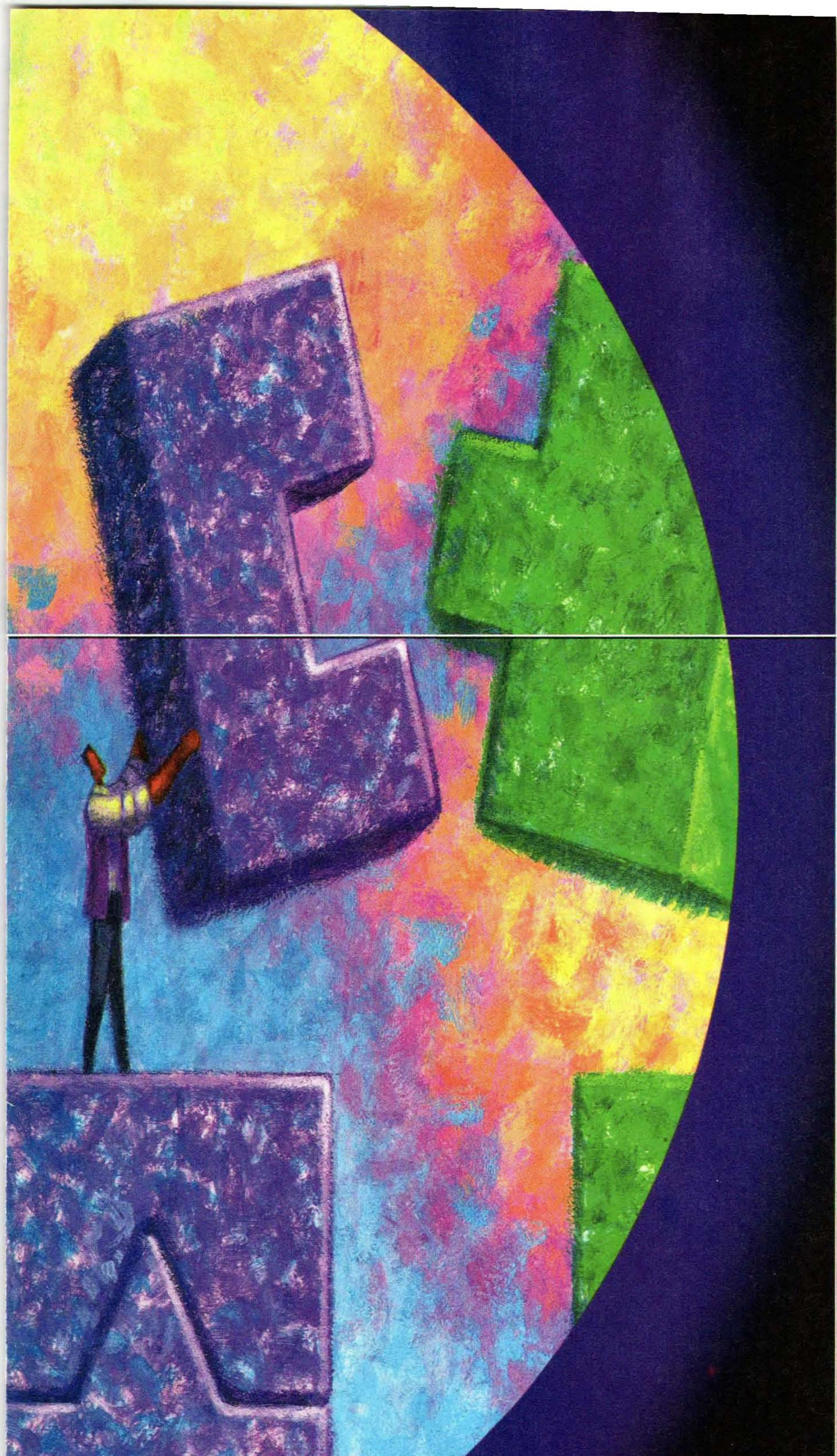


NEWS

Process Improvements Drive Device Advances

High-frequency devices and ICs continue to achieve new levels of performance thanks to enhancements in basic materials and semiconductor process technologies.

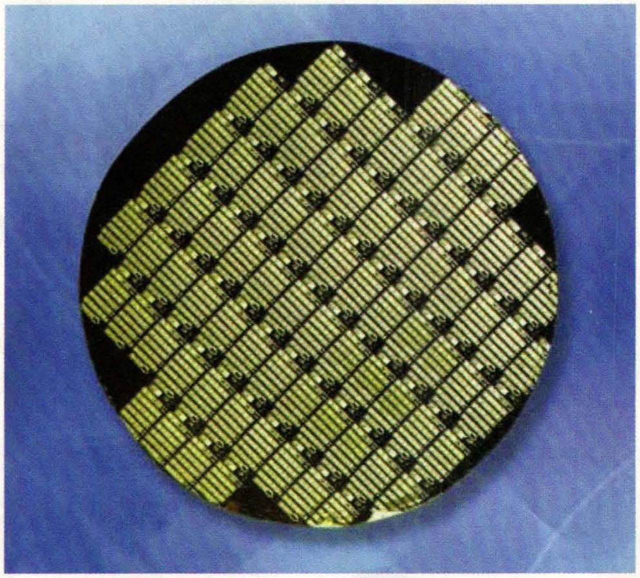
JACK BROWNE
Publisher/Editor

DAWN PRIOR
Editorial Assistant

Semiconductor processes and materials continue to improve, leading the way for steady advancements in discrete-device and integrated-circuit (IC) performance and value. Several decades ago, high-frequency devices were almost exclusively based on silicon materials. Today, gallium arsenide (GaAs) has matured into a semiconductor material for commercial, military, and even commercial products, and a host of other semiconductor materials, such as gallium nitride (GaN) and indium phosphide (InP), are finding application in strong niche markets. Even silicon has matured to the point where basic CMOS processing can now yield RF and microwave devices at frequencies once considered the exclusive realm of GaAs. And the "offspring" of basic silicon—silicon germanium (SiGe) and silicon carbide (SiC)—are beginning to fulfill the promise of earlier research claims.

The list of high-frequency semiconductor suppliers has never been longer **(see table)**. Driven in large part by expanding markets for Bluetooth, cellular, wireless-local-area-network (WLAN), radio-frequency-identification (RFID), and other large-volume applications, RF semiconductor suppliers offer everything from small-signal low-noise transistors and large-signal power transistors to complete radio receivers, transmitters, and transceivers on a chip. Although companies with their own semiconductor foundries still flourish, the number of "fabless" semiconductor companies (relying on outside foundries) has risen dramatically. Companies such as Hittite Microwave (Chelmsford, MA), for example, are not bound to any one semiconductor technology. Although founded by former Raytheon Company engineers with expertise in GaAs device design, Hittite has taking advantage of outside foundry services to develop a line of broadband 7-GHz direct modulator products and gain blocks based on SiGe (see October 2003, p. 78). Similarly, startup company Centellax has employed outside SiGe foundry services to fabricate its advanced fractional-N synthesizer design (see December 2003, p. 88).

How high can silicon go? That question certainly has come to haunt those with significant investments in GaAs foundries and semiconductor product lines. Although GaAs high-power transistors are well entrenched in a variety of terrestrial and satellite-communications bands from such suppliers as California Eastern Laboratories (NEC), Excelics Semiconductor, Fujitsu Compound Semiconductor, and Mitsubishi,



GaN process enhancements achieved by TriQuint Semiconductor working in conjunction with Lockheed Martin have resulted in new levels of power density and efficiency for GaN power transistors. (Photograph courtesy of TriQuint Semiconductor and Lockheed Martin.)

GaAs is being strongly challenged by SiGe and even traditional Si CMOS for lower-power (1 to 2 W) applications through about 5 GHz. For example, SiGe Semiconductors, one of the earlier adopters of SiGe technology, offers ICs and RangeCharger RF modules for IEEE 802.11a/b/g WLAN systems operating at 2.4 and 5 GHz. The fabless semiconductor company's 802.11b/g power amplifiers were chosen by Broadcom for that supplier's WLAN reference designs.

Companies currently offering SiGe-based semiconductors constitute a long and ever-growing list that includes Atmel, Hittite Microwave, IceFyre, Infineon Technologies, Inphi, Intersil, Maxim Integrated Products, SiGe Semiconductor, Sirenza Microdevices, and RF Micro Devices. Infineon's models BFP640 and BFP650 NPN transistors, for example, are based on the company's own 70-GHz SiGe process. The devices, developed for use in WLANs, feature noise figures rivaling those of low-noise GaAs MESFETs, with a noise figure of 0.65 dB at 1.8 GHz and 1.3 dB at 6 GHz for the BFP640 device.

IBM, one of the best-known merchant foundries for SiGe processing services, currently offers a variety of technologies geared to different applications. The BiCMOS 7HP SiGe process, for example, features self-aligned emitters, shallow and deep trench isolation, and high-speed transistors capable of cutoff frequencies to 120 GHz. The 180-nm-feature process is ideal for fabricating the high-gain heterojunction-bipolar transistors (HBTs) common to many wireless circuits. Similarly, Taiwan Semiconductor Manufacturing Company (TSMC) is a well-known merchant foundry of Si and SiGe processes.

At present, power devices based on SiGe are rare, although

the Electronic Sensors and Systems Sector of Northrop Grumman (www.es.northropgrumman.com) has developed a SiGe power transistor for air-traffic-control radar applications. The company's model WPTB48F2729C achieves better than 7 dB typical gain from 2.7 to 2.9 GHz with typical collector efficiency of 46 percent. Under Class C conditions, the SiGe HBT can generate more than 180 W output power when fed with pulsed (60-µs pulses at a 6-percent duty cycle) input signals.

Although SiGe can support high-power devices, it is the thermal characteristics of SiC that have made that material so attractive to developers of high-power transistors. As part of The SiC Program, NASA's Glenn Research Center has been one of the chief driving forces behind the development of high-power SiC device technology. For example, Rockwell Scientific now offers its model T4200 SiC power MESFET for applications to 3.6 GHz. The rugged transistor, with 12-dB typical gain and 25-W minimum output power at 2 GHz, achieves 40-percent drain efficiency at +50 VDC and 1200 mA. The device features a third-order intermodulation product of typically −30 dBc, making it well suited for applications in CDMA and WCDMA systems.

> ***Although SiGe can support high-power devices, it is the thermal characteristics of SiC that have made that material attractive to developers of high-power transistors.***

Cree Microwave, a supplier of SiC wafers and SiC MMIC foundry services, also offers SiC power transistors, such as its MESFET model CRF-24010 which is available in pill- and flange-style packages. The SiC power transistor boasts 10-W minimum output power at 1-dB compression with 15-dB typical small-signal gain at 2 GHz. The drain efficiency is typically 45 percent at +48 VDC and 250 mA, and the third-order intermodulation distortion is a respectable −31 dBc. In spite of its healthy output power, the device also achieves a minimum noise figure of 3.1 dB. (Cree also offers 600-V SiC Schottky diodes with fast switching speeds for reduction in size of EMI filters, for high-power electronic systems.)

In contrast, GaN devices are still largely in the research phase. With a strong push by the Office of Naval Research (ONR, www.onr.navy.mil), research on GaN high-power devices is being

pursued by more than 100 laboratories at present, including major defense contractors such as the Information and Electronic Warfare Systems division of BAE Systems (www.baesystems.com) and the Electronic Sensors and Systems Sector of Northrop Grumman. While the material holds great promise for extremely high-power discrete transistors at microwave frequencies, GaN wafers are still expensive and generally only 2 inches in diameter compared to wafers as large as 6 and 12 inches in diameter, respectively, for GaAs and silicon wafers. Recently, however, TriQuint Semiconductor and defense contractor Lockheed Martin announced major strides in the development of a power GaN high-electron-mobility-transistor (HEMT) device. At an undisclosed frequency, the firms noted a power density of 11.7 W/mm, output power of +34 dBm, small-signal gain of 9.83 dB, and power-added efficiency of better than 50 percent **(see figure)**. According to Dr. Mahesh Kumar, director of Research and Technology for Lockheed Martin Maritime Systems and Sensors business (Moorestown, NJ), "Gallium nitride will redefine what is possible by providing our customers the reliable, compact, high-powered technology they need to field solid-state phased-array radar, space systems, and missiles to protect against emerging threats."

One semiconductor company now offering GaN devices is relative newcomer Nitronex Corp. (Raleigh, NC). Founded in 1999 by Dr. Kevin Linthicum and three other graduate students from NC State University, the company is one of the best-funded private firms in North Carolina, having raised more than $45 million in funding. The company's prototype discrete devices include the +28-VDC models N10 and N20 RF power transistors for WCDMA applications. The former delivers more than 10 W output power while the latter is designed for more than 20 W of WCDMA output power; both flange-package-mounted transistors exhibit 11.5-dB gain from 1800 to 2200 MHz with 25-percent typical efficiency. The company plans

RF/microwave semiconductor suppliers at a glance

COMPANY	PRODUCTS	WEBSITE
Advanced Power Technology RF	Si power transistors, module	advancedpower.com
Agere Systems	Si discretes and ICs	agere.com
Agilent Technologies	GaAs, Si ICs, discretes	semiconductor.agilent.com
ANADIGICS	GaAs, InGaP ICs	anadigics.com
Analog Devices	Si ICs	analog.com
Araftek	GaAs, Si ICs, modules	araftek.com
Atmel	Si ICs	atmel.com
Boeing	GaAas, InP, and SiGe design services	boeing.com
California Eastern Labs (NEC)	GaAs, Si discretes, ICs	cel.com
Cambridge Silicon Radio	Si (Bluetooth) ICs	csr.com
Celeritek	InGaP, GaAs ICs	celeritek.com
Chipcon	Si ICs	chipcon.com
Cree	SiC power transistors	cree.com
Cypress Semiconductor	Si (2.4-GHz radio) ICs	cypress.com
Discovery Semiconductors	InGaAs optical ICs	chipsat.com
EiC	InGaP ICs, modules	eiccorp.com
Excelics Semiconductor	GaAs discretes and ICs	excelics.com
Fairchild Semiconductor	GaAs ICs	fairchildsemi.com
Filtronic Solid State	GaAs discretes, ICs, modules	filss.com
Fujitsu Compound Semiconductor	GaAs discretes, ICs	fcsi.fujitsu.com
Fujitsu Microelectronics	Si ICs	fma.fujitsu.com
Future Electronics (distributor)	Si, GaAs discretes, ICs	futureelectronics/rf
Global Communications Semiconductors	InP HBT foundry services	gcsincorp.com
Hitachi Cable	GaAs wafers	hitachi-cable.com
Hitachi Semiconductor	Si (RFID) ICs	hitachi.co.jp
Hittite Microwave	SiGe, GaAs ICs	hittite.com
Honeywell	fiber-optic ICs	honeywell.com
IBM	Si and SiGe foundry	www-306.ibm.com/chips
IceFyre Semiconductor	GaAs, Si ICs (WLAN)	icefyre.com
Infineon Technologies	Si ICs	infineon.com
Inphi	SiGe, GaAs, Si, InP ICs	inphi-corp.com
Intersil	Si analog ICs	intersil.com
ISG Broadband	SiICs	isgbroadband.com
Knox Semiconductor	Si diodes	knoxsemiconductor.com
Linear Technology	Si ICs	linear.com
M/A-COM	GaAs ICs, foundry services	macom.com
Maxim Integrated Products	Si ICs	maxim-ic.com
Micrel Semiconductor	Si ICs	micrel.com
Microwave Technology	GaAs discretes, ICs, modules	mwtinc.com
Mimix Broadband	GaAs ICs	mimixbroadband.com
Mitsubishi Electric Semiconductor	Si, GaAs discretes, ICs	mitsubishichips.com
Motorola Semiconductor	Si discretes, ICs	motorola.com/rf
Murata North America	GaAs ICs, modules	www.murata-northamerica.com
National Semiconductor	Si ICs	national.com

COMPANY	PRODUCTS	WEBSITE
Nitronix Corp.	GaN discretes	nitronix.com
NJR Corporation	Si (video and IF) ICs	njr.com
Northrop Grumman	SiGe power transistors, GaAs foundry services	es.northropgrumman.com
Oki Semiconductor	GaAs and Si ICs	okisemi.com
ON Semiconductor	clock management, power management	onsemi.com
Peregrine Semiconductor	Si-on-sapphire ICs	peregrine-semi.com
Philips Semiconductor	Si discretes, ICs	philips.com
Point-Nine Technologies	Si power transistors	pointnine.com
Polyfet RF Devices	Si power transistors	polyfet.com
QUALCOMM	Si (CDMA) ICs	qualcomm.com
RF Micro Devices	GaAs Si, SiGe ICs and modules	rfmd.com
Richardson Electronics (distributor)	Si, GaAs discretes, ICs	rell.com
Rockwell Scientific	SiC power transistors, GaAs ICs	rockwellscientific.com
Seme Lab	Si transistors, diodes	semelab.co.uk
Siemens	Si discretes, ICs	siemens.com
SiGe Semiconductor	SiGe ICs	sige.com
Silicon Laboratories	Si, SiGe, GaAs	silabs.com
Sirenza Microdevices	Si, SiGe, GaAs discretes, modules, ICs	sirenza.com
Skyworks Solutions	GaAs, Si discretes, ICs, modules	skyworksinc.com
Sony Semiconductor	GaAs, Si discretes, ICs	products.sel.sony.com
STMicroelectronics	Si power transistors	st.com/rf
Sumitomo Electric USA	GaAs, InP wafers	sumitomoelectricusa.com
Taiwan Semiconductor Manufacturing Co. (TSMC)	Si and SiGe foundry	tsmc.com
Teledyne Wireless	GaAs ICs (amplifiers)	teledynewireless.com
Temex Electronics	Si diodes, modules	temex-components.com
Texas Instruments	Si ICs	ti.com
Toshiba America Electronic Components	GaAs, Si discretes, and ICs	toshiba.com/taec
TriQuint Semiconductor	GaAs ICs, foundry services	triquint.com
US Monolithics	GaAs (mm-wave amplifier) ICs and modules	usmonolithics.com
Velocium	GaAs, InP ICs, foundry	velocium.com
Vitesse Semiconductor	GaAs digital ICs	vitesse.com
WIN Semiconductors	GaAs foundry	winsemiconductors.com
WJ Communications	GaAs discretes, ICs, foundry services	wjcommunications.com
Xemics	Si ICs	xemics.com
Zarlink Semiconductor	Si bipolar foundry services	zarlink.com
Zeevo	Si (Bluetooth) ICs	zeevo.com

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Model	Freq. ■ (MHz)	Gain (dB) 0.1GHz	Power Out @1dB Comp. (dBm)	Dynamic Range NF (dB)	Dynamic Range IP3 (dBm)	Thermal Resist. θ jc, °C/W	DC Operating Pwr. Current (mA)	DC Operating Pwr. Device Volt	Price $ea. (25 Qty.)
Gali 1	DC-8000	12.7	12.2	4.5	27	108	40	3.4	.99
Gali 21	DC-8000	14.3	12.6	4.0	27	128	40	3.5	.99
Gali 2	DC-8000	16.2	12.9	4.6	27	101	40	3.5	.99
Gali 33	DC-4000	19.3	13.4	3.9	28	110	40	4.3	.99
Gali S66	DC-3000	22	2.8	2.7	18	136	16	3.5	.99
Gali 3	DC-3000	22.4	12.5	3.5	25	127	35	3.3	.99
Gali 6F	DC-4000	12.1	15.8	4.5	35.5	93	50	4.8	1.29
Gali 4F	DC-4000	14.3	15.3	4.0	32	93	50	4.4	1.29
Gali 51F	DC-4000	18.0	15.9	3.5	32	78	50	4.4	1.29
Gali 5F	DC-4000	20.4	15.7	3.5	31.5	103	50	4.3	1.29
Gali 55	DC-4000	21.9	15.0	3.3	28.5	100	50	4.3	1.29
Gali 52	DC-2000	22.9	15.5	2.7	32	85	50	4.4	1.29
Gali 6	DC-4000	12.2	18.2	4.5	35.5	93	70	5.0	1.49
Gali 4	DC-4000	14.4	17.5	4.0	34	93	65	4.6	1.49
Gali 51	DC-4000	18.1	18.0	3.5	35	78	65	4.5	1.49
Gali 5	DC-4000	20.6	18.0	3.5	35	103	65	4.4	1.49

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on releasing a 36-W WCDMA power transistor later this year.

At higher microwave and millimeter-wave frequencies, power generation is still a challenge, and more mature semiconductor materials such as GaAs and InP are the substrates of choice for most devices. Velocium, formerly a part of TRW and now a Northrop Grumman company, offers both GaAs and InP foundry services, with one-tenth-micron HEMT GaAs and InP devices featuring cutoff frequencies as high as 120 and 180 GHz, respectively. The company recently announced the model APH462 two-stage 15-to-27-GHz GaAs amplifier for point-to-point digital radios at 18, 23, and 26 GHz. It features 17-dB gain and more than 1-W saturated output power over the operating band.

Even at lower frequencies, GaAs MMICs still comprise a large portion of the RF active devices used in cellular handsets, a factor that motivated Fairchild Semiconductor's acquisition of the RF Components Div. of Raytheon Company last October.

At higher microwave and millimeter-wave frequencies, power generation is still a problem, and more mature semiconductor materials are still the substrates of choice for most devices.

The move, which strengthened Fairchild's presence in the wireless-communications market, provides the semiconductor pioneer and leading supplier of power semiconductors with a strong foothold in a growing market. According to research firm Strategy Analytics, the total market for GaAs power amplifiers is projected to grow to between $0.77 and $1.2 billion by 2006, at a compound annual growth rate of 16 percent. Fairchild also acquired Raytheon's foundry partnership and an equity stake in WIN Semiconductor.

In addition, silicon discrete devices, whether as bipolars, MOSFETS, or LDMOS devices, still dominate applications requiring tube-like power through about 1200 MHz. In pulsed avionics applications, for example, LDMOS transistors from Advanced Power Technology provide output power to 300 W at 1090 MHz. The company also offers MODE-S transistors for pulsed outputs to 1100 W at 1090 MHz. MRF

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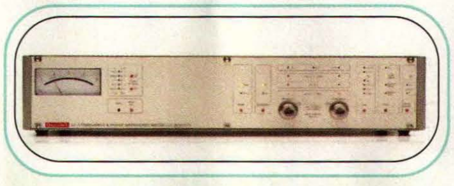

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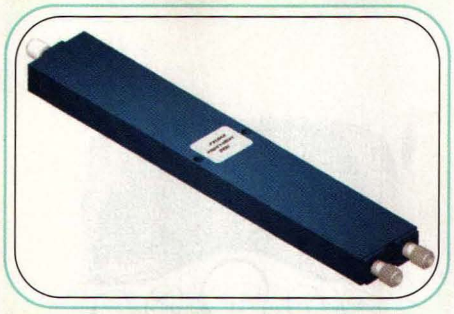

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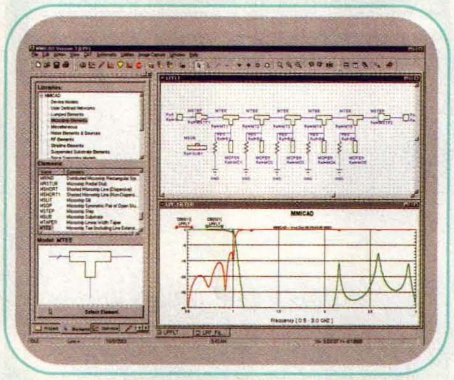

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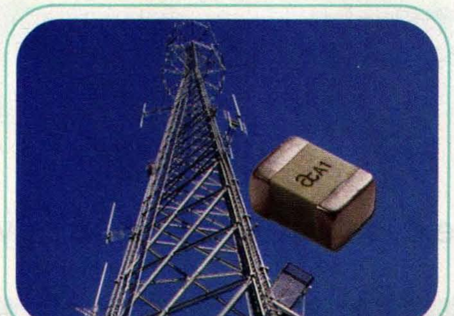

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Optotek Ltd., 62 Steacie Dr., Ottawa, Ontario K2K 2A9, Canada; (613) 591-0336, (800) 361-2911 (North America), FAX: (613) 591-0584, e-mail: sales@optotek.com, Internet: www.optotek.com.

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RFMD Reports Record Revenue

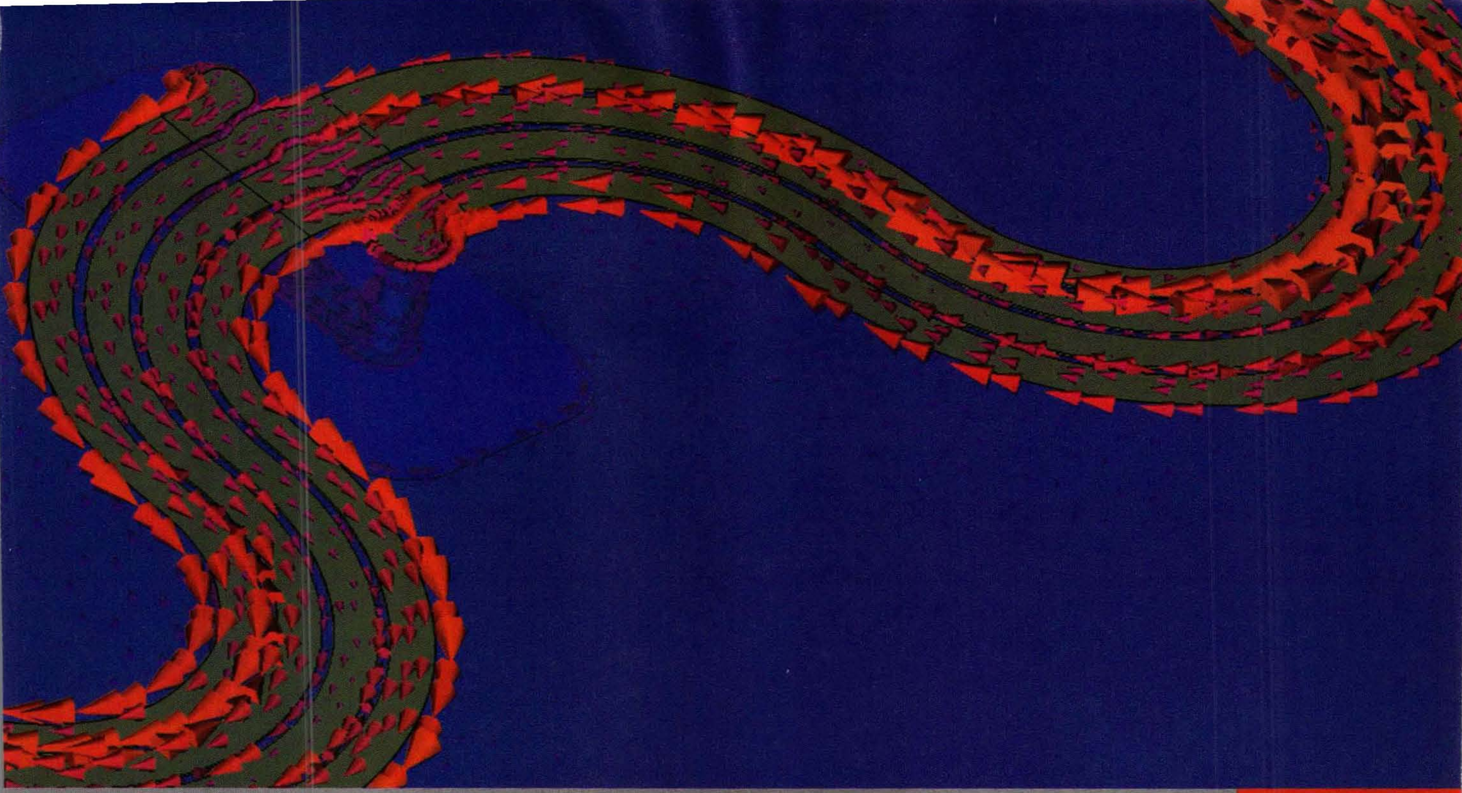
RF MICRO DEVICES, INC., a provider of proprietary RF integrated circuits (RF ICs) for wireless-communications applications, has reported financial results for the fiscal 2004 third quarter, which ended on December 31, 2003.

Revenue for the quarter was $193.0 million, an increase of 32.3 percent versus revenue of $145.8 million for the corresponding quarter of fiscal 2003, and a sequential increase of 18.1 percent versus revenue of $163.5 million for the quarter ended September 30, 2003. The record quarterly revenue reflected strength in the cellular handset market. Additionally, the December 2003 quarter contained 14 weeks, versus 13 weeks in the quarter that ended on September 30, 2003.

Gross profit for the quarter was $80.4 million, an increase of 47.8 percent versus $54.4 million for the prior-year period, and a sequential increase of approximately 26 percent from $63.8 million for the September 2003 quarter. Gross profit margin increased sequentially to 41.7 percent versus 39 percent in the prior quarter and 37.3 percent in the corresponding quarter of fiscal 2003. The year-over-year and sequential increases in gross profit margin were primarily attributable to higher volumes, improved yields, and cost savings from the conversion from four-inch to six-inch gallium-arsenide (GaAs) wafer fabrication.

RFMD currently anticipates March 2004 quarterly revenue of approximately $153 million to $162 million. Additionally, the company currently expects diluted earnings per share in the range of approximately $0.02 to $0.04.

Bob Bruggeworth, president and CEO of RFMD, says, "We're extremely pleased to announce all-time quarterly records in revenue and earnings per share, driven primarily by seasonal strength in the handset market, gross margin improvement initiatives, and expense control across the organization. Our performance in cellular power amplifiers is especially noteworthy, as evidenced by market-share gains and our introduction of innovative new products, such as our next-generation PowerStar® RF3146 power-amplifier module. MRF



CONTRACTS

Northrup Grumman Corp.—Has been selected by the US Department of Homeland Security to participate in the next phase of the Department's program to develop and test anti-missile systems designed to protect commercial aircraft.

Northrup Grumman's anti-missile devices are currently deployed on a variety of US and UK military aircraft operating worldwide, including C-17 and C-130 military transports. The company will adapt its Directional Infrared Countermeasure (DIRCM) systems to provide effective and economical protection for commercial aircraft application.

Work on the contract will be based at Northrup Grumann's Defense Systems Division in Rolling Meadows, IL.

Raytheon JPS Communications—Was awarded a contract with the General Services Administration (GSA) to make its technology available to the government community.

JPS offers an array of communications products and services designed to enhance the effectiveness of communications systems. Their product portfolio includes: interoperability solutions, VoIP technology, radio/telephone interface units, voting products, and noise-reduction systems.

BAE Systems—Has been awarded a three-year, $4.5 million contract by the Department of the Interior for the US Army to improve producibility and lower the cost of advanced MicroIR™ infrared focal plane arrays (FPAs).

BAE Systems IR Imaging Systems (IRIS) was the first to develop and demonstrate a small pixel, uncooled, infrared camera, making television-like imagery possible. The camera has more than 300,000 pixels. Under this contract, IRIS will improve the producibility and reduce the manufacturing cost of the FPAs by a factor of eight.

EMS Technologies, Inc.—Announced that it has received the fourth flight set award from Alcatel Space, a subsidiary of Alcatel, for the high-power output assembly (HPOA) used by XM Satellite Radio. The latest flight set, valued at $1.5 million, will perform the signal combining on XM's geostationary satellites, supporting the satellite radio service transmission of 101 channels of digital radio to subscribers nationwide.

FRESH STARTS

Paratek Microwave—Has received $15 million in new Series B funding. In addition, $8.5 million of previously raised debt was converted into equity in conjunction with the Series B funding. Paratek will use the funds to expand marketing and sales efforts, and to expedite development of additional commercial products. The funds were raised from five private equity firms led by Polaris Venture Partners. Other investors include Morgenthaler Ventures, Novak Biddle Venture Partners, Investor Growth Capital, and ABS Ventures.

Microwave Development Corp.—Announced the appointment of a new sales representative organization, Tekmar Sales, Inc. Tekmar Sales will cover the metropolitan New York and Northern New Jersey area.

Terabeam Corp.—Recently launched a new website. The site is located at www.terabeam-hxi.com.

Amphenol RF—Relocated its headquarters to a new facility in Danbury, CT on December 15, 2003. The new headquarters is located at 4 Old Newtown Road, Danbury, CT, just off of Exit 8 of Route 84.

AMI Semiconductor—Announced its associate membership to the FlexRay Consortium. By becoming a member of the Consortium, AMIS has access to the FlexRay technology, with a free-of-charge, royalty-free license for automotive applications. In addition, the company will have access to early industry information and the results of FlexRay developments, along with the FlexRay-related IP of all other FlexRay members.

Modelithics, Inc.—Appointed Technical Software Service (TSS) in Weissenhorn, Germany as a reseller for its EDA RF/microwave model library software, and a representative for Modelithics RF/microwave measurement and modeling services. TSS represents Modelithics in Germany, Austria, and Switzerland.

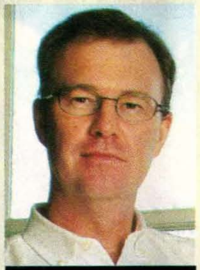
RF Micro Devices, Inc.—Has begun shipments of a power-amplifier (PA) module and driver IQ modulator for use in the Sony Ericsson GC82 Enhanced Data for Global Evolution (EDGE) PC card.

The GC82 EDGE PC card supports EDGE service on the AT&T Wireless network, which enables consumers to achieve fast cellular connections on the wireless Internet via handsets, laptop computers, PDAs, and other wireless devices. The GC82 EDGE PC card fits in the PCMCIA slot of laptop computers and has been demonstrated by AT&T Wireless to achieve average download speedsa of approximately 100 to 130 kb/s, with maximum speeds of up to 200 kb/s.

Hittite Microwave Corp.—Announced the appointment of a new sales representative firm to serve customers in Japan. Saint Technology Corp., headquartered in Tokyo, Japan, was established in 1998 to act as a specialist Japanese representative for electronic-component manufacturers. Saint Technology's areas of expertise include: Telecom/Datacom, ATE/Instrumentation, PC/PDA, Wireless (AV Streaming, LMDS, PCS, Broadcasting), and Ubiquitous Internet Access.

Saint will support Hittite's direct sales channel in Japan by focusing promotion on a select group of key customers and supplementing Hittite's current Japanese representative, SEKI Technotron. Saint Technology can be contacted via telephone at +81-3-5330-6411, via fax at +81-3-5330-6414, or by e-mail at info@saint-tec.co.jp.

Maury Microwave Corp.—Added a new international sales representative. ALTAIX Electronica will cover the countries of Spain and Portugal. For details about ALTAIX, contact Pedro Martinez, director of sales, at 34-91-440-0385 or by e-mail at pmartinez@altaix.com. MRF



SWAHN

picoChip Names Swahn As Company's New CEO

picoChip Designs Ltd. has appointed ANDERS SWAHN to the position of CEO. Prior to taking on his new position at picoChip, Swahn served as vice president and general manager for one of PMC Sierra's Carrier Switching Divisions.

Hittite Microwave Corp.—STEVE DALY to president; formerly director of sales. Also, MIKE KOECHLIN to the position of executive vice president; formerly business development manager. In addition, NORM HILDRETH to vice president of sales and marketing; formerly director of product development.

ANADIGICS, Inc.—BRIAN HURST to vice president of worldwide sales and marketing; formerly vice president and general manager of sales and marketing for the Americas at National Semiconductor Corp.

Proxim Corp.—MICHAEL P. RESSNER to the board of directors; formerly held several senior management positions at Nortel Networks. Also, FRANK PLASTINA to chairman of the board; remains as CEO.

Xovix, Inc.—JOE GRIFFIN to vice president of sales and business development; formerly employed at GCS-Team, a high-tech consultancy which he co-founded.

Lucent Technologies—JOHN P. GIERE to chief marketing officer; formerly vice president of business development and new sales push at Ericsson.

Amphenol RF—ADAM NORWITT to director for global RF products and general manager; formerly director for interconnect systems, Asia.

InterDigital Communications Corp.—ED KAMINS to the board of directors; continues as chief information officer and senior vice president of Avnet, Inc.

Park Electrochemical Corp.—VITO A. TANZI to product director; formerly plant manager for Aeroflex MIC Technology Corp., Thin Film Division.

Boingo Wireless—KAREN BLACK to senior vice president of engineering; formerly vice president and general manager at Symantec Corp.

IceFyre Semiconductor, Inc.—DOUG SANDERSON to vice president of engineering; formerly director of digital design.

Geotest-Marvin Test Systems, Inc.—GRETCHEN ADIN to marketing program manager; formerly employed in the medical-device, medical-intelligence, and A/V industries.

Silicon Laboratories, Inc.—DAN ARTUSI to president and CEO; formerly COO.

Glenayre Technologies, Inc.—KRISTOPHER A. WOOD to vice chairman and chief acquisitions officer; formerly a managing director with Chancery Lane Capital LLC.

Andrew Corp.—ROGER J. MANKA to group president of worldwide sales; formerly vice president of worldwide sales at Commworks, a 3Com company.

SiGe Semiconductor—ROBERT FLEMING to chairman of the board; continues as general partner of Prism Venture Partners.

FLEMING

ROBERTS

AMI Semiconductor—ALUN ROBERTS to strategic marketing director; formerly marketing director for Legerity, Inc.'s High-Performance Analog business.

Indium Corp. of America—KARL PFLUKE to market development specialist; formerly technical support engineer. MRF

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Technology Strategy for R&D and Product Development
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Course Location: California Institute of Technology Industrial Relations Center
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Provisioning ADSL: From DSLAM To Doorstep
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e-mail: danbeck@epd.engr.wisc.edu
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Antenna Parameter Measurements By Near-Field Techniques
April 20-22 (Boulder, CO)
National Institute of Standards and Technology (NIST) Boulder Laboratories
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►MEETINGS

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CeBit 2004
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e-mail: cebit@hfusa.com
Internet: www.hfusa.com/cebit

electronicaUSA with the Embedded Systems Conference
March 29-April 1 (San Francisco, CA)
Moscone Convention Center
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2004 IEEE Compound Semiconductor IC Symposium
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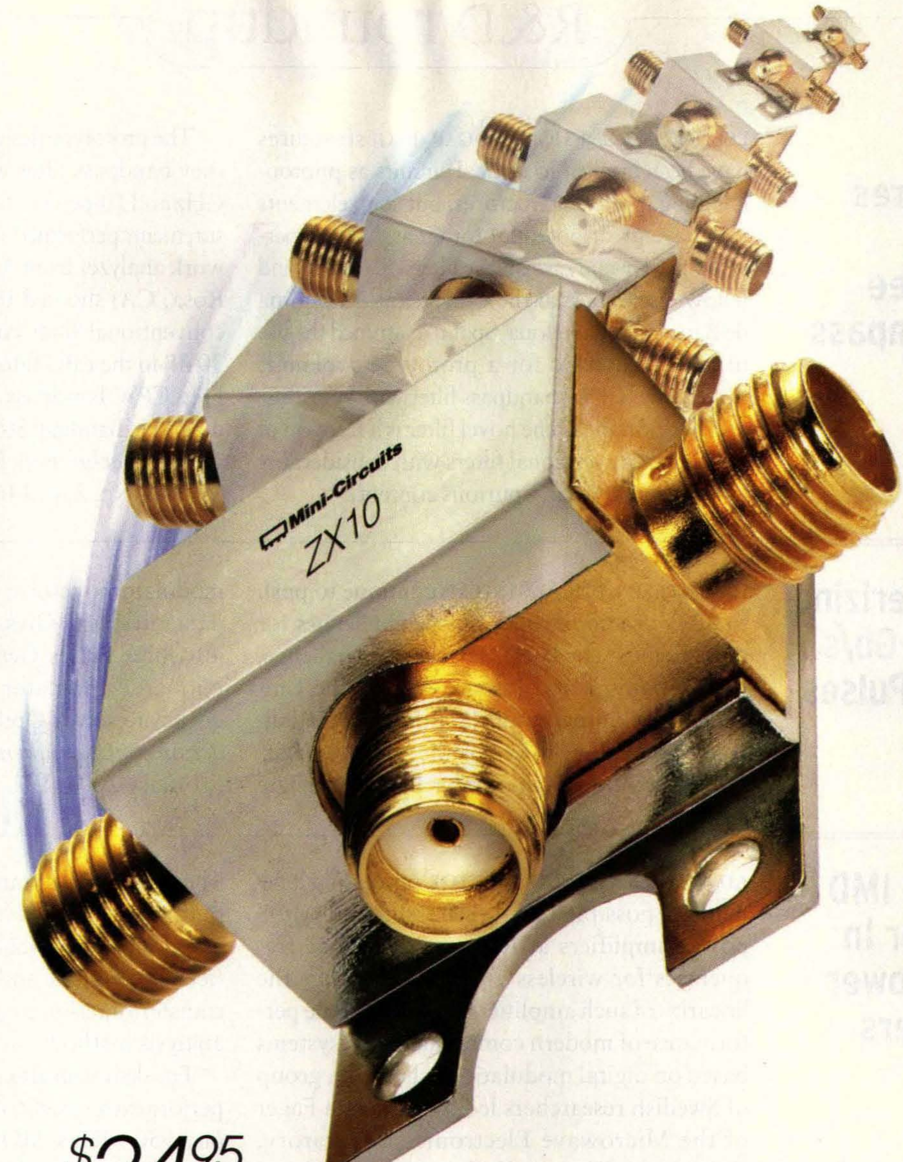

Mini-Circuits
ZX10

EBG Structures Form Spur-Free CPW Banpass Filters

ELECTROMAGNETIC-BANDGAP (EBG) structures have been applied to optical circuits as photonic-bandgap (PBG) structures, but such elements also have great potential for creating high-performance RF and microwave filters. F. Martin and fellow researchers at the Universitat Autonoma de Barcelona (Barcelona, Spain) examined the use of EBG structures for a prototype coplanar-waveguide (CPW) bandpass filter with spurious-free performance. The novel filter is a fraction of the size of conventional filters with considerably less parasitic effects (spurious content).

The prototype design is a fourth-order Chebyshev bandpass filter with center frequency of 6 GHz and 10-percent fractional bandwidth. Measurements performed on a commercial vector network analyzer from Agilent Technologies (Santa Rosa, CA) showed that spurious content in a conventional filter could be reduced by about 30 dB in the EBG filter. See "Compact Spurious Free CPW Bandpass Filters Based on Electromagnetic Bandgap Structures," *Microwave and Optical Technology Letters*, January 20, 2004, Vol. 40, No. 2, p. 146 .

Characterizing Fast 40-Gb/s Optical Pulses

HIGH-SPEED OPTICAL SYSTEMS continue to push to 40 Gb/s and beyond, posing challenges for measurement engineers. To meet the challenge, Benn Thomsen and associates from the University of Southampton (Southampton, England) showed how to exploit the nonlinear characteristics of a Mach-Zender lithium-niobate modulator to resolve fast optical signals even at data rates to 80 Gb/s. See "Characterization of 40-Gbit/s Pulses Generating Using a Lithium Niobate Modulator at 1550 nm Using Frequency Resolved Optical Gating," *IEEE Transactions on Instrumentation and Measurement*, February 2004, Vol. 53, No. 1, p. 186.

Analyze IMD Behavior In CMOS Power Amplifiers

ADVANCES IN SEMICONDUCTOR processing have made it possible to fabricate silicon CMOS power amplifiers at RF and microwave frequencies for wireless applications. Since the linearity of such amplifiers is critical to the performance of modern communications systems based on digital modulation schemes, a group of Swedish researchers led by Christian Fager of the Microwave Electronics Laboratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology (Goteborg, Sweden) performed a comprehensive analysis on the nonlinear intermodulation distortion (IMD) behavior of CMOS-based RF power amplifiers.

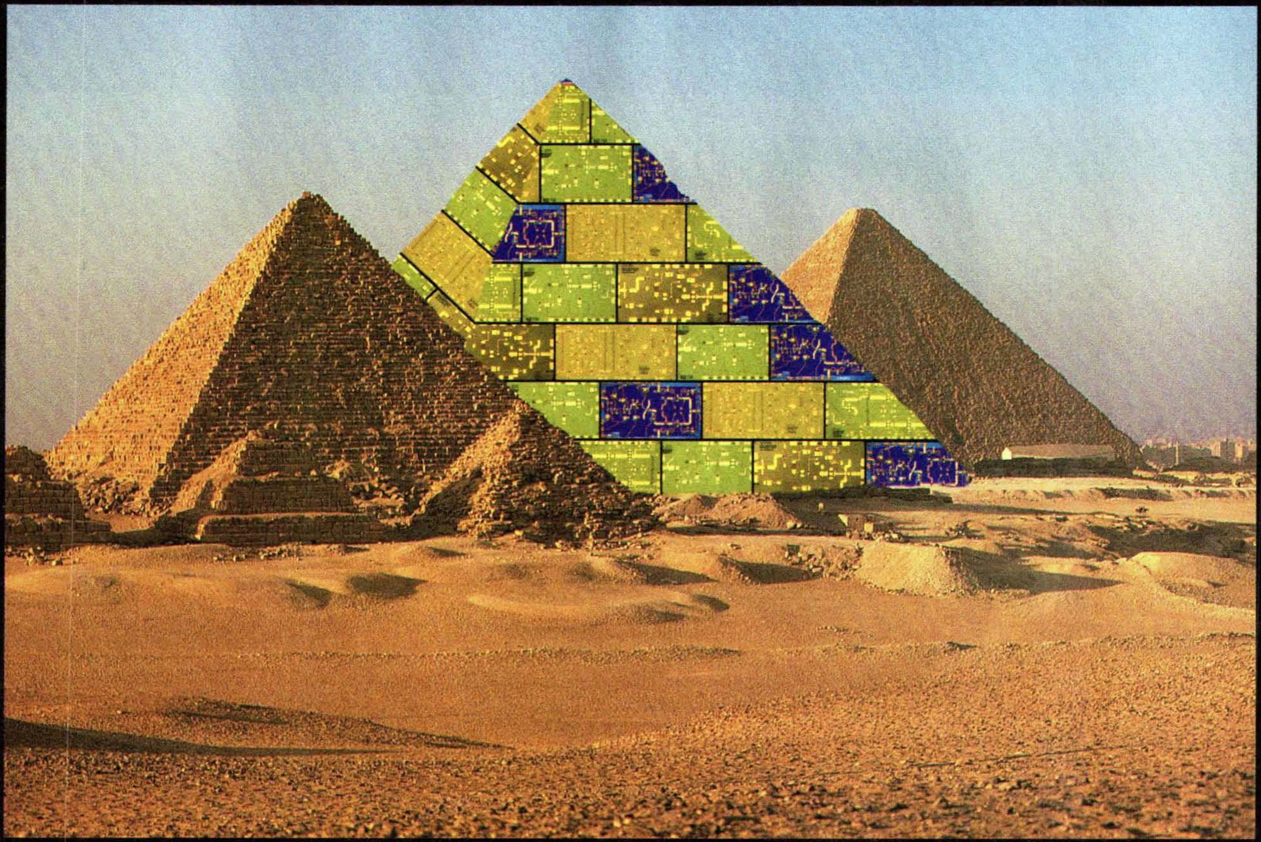
The researchers used analytical methods to examine both the small- and large-signal IMD behavior of MOSFET-based power amplifiers. They developed a transfer function based on the output current as a function of the input voltage along the line load where the power amplifier is operated, and then approximated the transfer function to derive a large-signal IMD analysis method.

For demonstration purposes, the researchers performed a variety of wideband measurements on a 950-MHz CMOS power amplifier, including a study of amplifier performance under different bias classes (Classes A, AB, and C), in order to validate their theory and analysis. They were also able to apply the BSIM3v3 nonlinear MOSFET model to predict IMD performance

See "A Comprehensive Analysis of IMD Behavior in RF CMOS Power Amplifiers," *IEEE Journal of Solid-State Circuits*, January 2004, Vol. 39, No. 1, p. 24.

Micromachined Microstrip Reaches MM-Waves

PRACTICAL MILLIMETER-WAVE CIRCUITS would clear the way for a host of applications at higher frequencies, including radio-frequency identification (RFID), networks, and short-range communications. With this in mind, Han-Shih Lee and co-workers at the Millimeter-Wave Innovation Technology Research Center (MINT) of Dongguk University (Seoul, Korea) set about to develop a new GaAs-based micromachined microstrip line based on RF microelectromechanical-system (MEMS) techniques. The new transmission line is well suited for use in monolithic-microwave integrated circuits (MMICs) working at microwave and millimeter-wave frequencies. The dielectrically supported air-gapped microstrip line was fabricated on a 680-µm-thick GaAs substrate and tested on a commercial vector network analyzer. Measurements on several different configurations show low signal losses from 100 MHz to 50 GHz. See "New Micromachined Microstrip Transmission Lines for Application in Millimeter-Wave Circuits," *Microwave and Optical Technology Letters*, January 5, 2004, Vol. 40, No. 1, p. 6.



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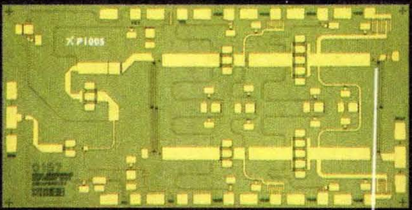

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DESIGN

Assessing Multicarrier Direct-Conversion Transmitters

Careful component selection can make direct-conversion architectures practical for multicarrier WCDMA and CDMA2000 cellular base stations.

Direct-conversion transmitters appeal to designers of wireless systems for their simplicity and low cost. Unfortunately, the simple architecture does not allow the filtering of broadband noise, images and spurious components typically executed at intermediate frequencies (IFs) in a more complex superheterodyne transmitter. For designers to migrate single-carrier base stations to multicarrier architectures using direct-conversion approaches, they must use components with high output compression and low noise. What follows is an examination of the direct-conversion approach for multicarrier WCDMA and CDMA2000, with particular attention on that critical component, the in-phase/quadrature (I/Q) modulator.

In a single-carrier WCDMA system **(Fig. 1)**, a base station typically transmits at carrier power levels to +46 dBm (40 W). The 3GPP standard requires that

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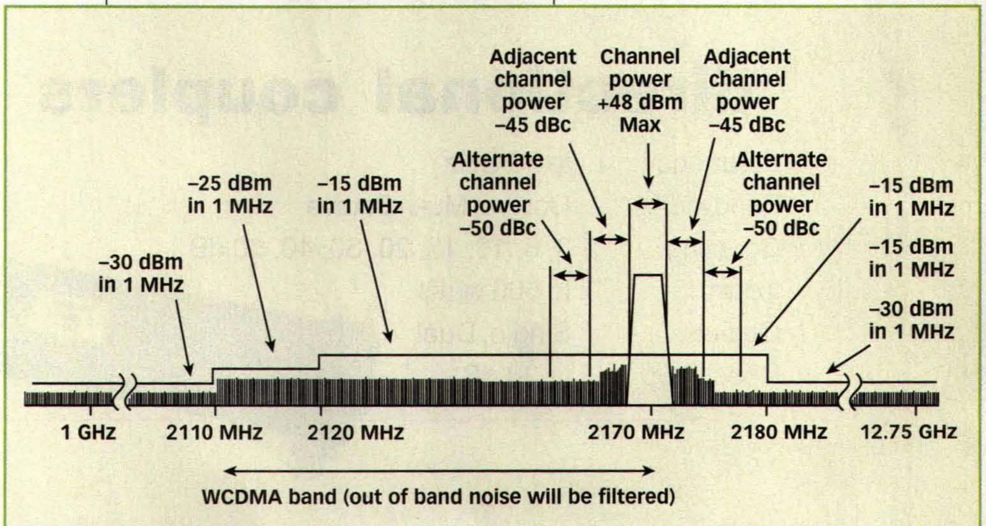
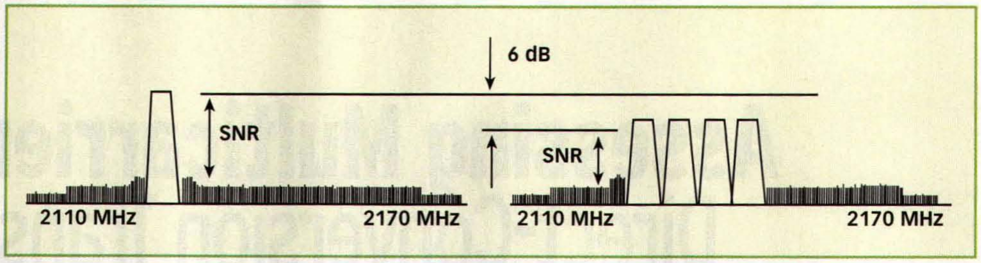


1. A WCDMA base-station transmitting a single carrier must create minimal interference within the 60-MHz transmission band (2110 to 2170 MHz or 1930 to 1990 MHz). Close to the carrier, the ACPR and alternate-channel power ratio must be no greater than −45 and −50 dBc, respectively. At the band edges, the base station must limit noise emissions to −30 dBm (in a 1-MHz bandwidth).

the power in the adjacent and alternate channels be no greater than –45 and –50 dBc, respectively (the carrier power and adjacent/alternate channel power are both measured in a 3.84-MHz bandwidth).[1] To achieve such performance, components are backed off from their maximum power levels, and predistortion techniques are typically used in the power amplifier for improved linearity. Further from the carrier, performance requirements are dominated by the noise-floor specifications (or spurious emissions).



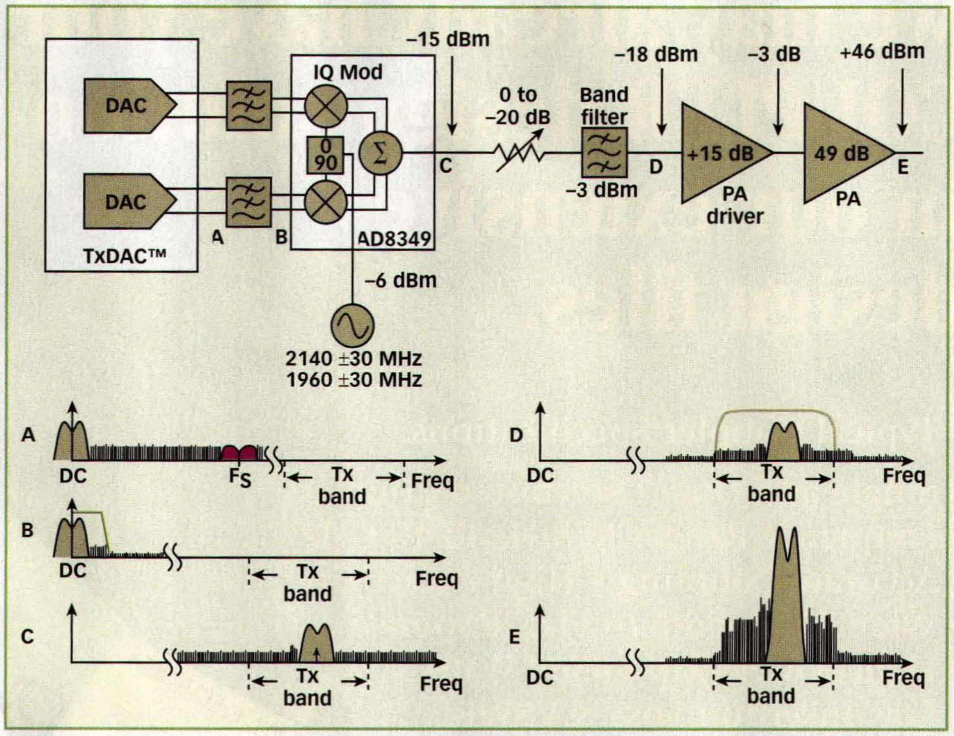
2. In a four-carrier WCDMA base station, the overall output power remains the same at +46 dBm, forcing the per-carrier power down by 6 dB. The ACLR and noise-floor requirements remain the same.

For example, at carrier offsets to 50 MHz, noise or spurious components, measured in a 1-MHz bandwidth, can be no greater than –15 dBm. At greater offsets from the carrier, requirements are more stringent, with the worst case at 60 MHz offset from the carrier (or at the edge of the band, whichever comes first); at the 60 MHz offset, the noise floor must be no greater than –30 dBm (1-MHz bandwidth).

Figure 2 compares single-carrier (left) and multiple-carrier (right) transmitter spectra. If the same model power amplifier is used in both systems, the per-carrier must be reduced in the four-carrier system to maintain a total output-power level of +46 dBm, resulting in multiple carriers with transmit powers of +40 dBm. For both approaches, the 3GPP standard still requires adjacent- and alternate-channel power ratios of –45 and –50 dBc, respectively, and a noise floor of –30 dBm.

As the power of each carrier is reduced by 6 dB, the resulting intermodulation distortion (IMD) in adjacent channels is also reduced as the distance to the system's third-order intercept point and compression point increases. This suggests that the adjacent-channel leakage ratio

(ACLR) should improve. However, because the noise floor remains relatively constant, the signal-to-noise ratio (SNR) degrades and begins to affect the ACLR (in the single-carrier case, the ACLR is dominated by distortion). Also, even though the per-carrier power is lower than for single-carrier case, the four carriers modulate each other and contribute to ACLR. The net result is that the ACLR will degrade as a particular hardware configuration is alternately driven by a single-carrier signal and by a multi-carrier signal with the same total power. For optimum performance, multi-carrier systems require signal chains that have the highest possible signal-to-noise ratio.



3. In a direct-conversion transmitter, there is no further opportunity for narrowband filtering once the baseband I and Q components have been lowpass filtered. Nonideal behavior in the I/Q modulator, such as LO leakage and amplitude imbalances degrade the EVM of the modulated carrier.

Figure 3 shows a block diagram of a direct-conversion transmitter, with representations of the signal spectrum along the designated points in the signal chain. The dual DACs create a baseband I/Q spectrum (A), while lowpass filters following the DACs eliminate Nyquist images and noise (B). Although this noise filtering has traditionally been less critical, the emergence of low-noise I/Q modulators (with noise floors rivaling even 14- or 16-b DACs) has made noise filtering more meaningful. This suggests that the corner frequency of the filter be as close as possible to the edge of the spectrum (this will help to improve in-band noise at the antenna). However, a trade-off must be made as placing the 3-dB corner of the filter too close to the edge of the spectrum will give in-channel group delay variations and will degrade error vector magnitude (EVM).

The filtered baseband signals drive the I and Q inputs of a quadrature modulator which is also driven by a local oscillator (LO) with frequency centered at the desired output frequency. The LO is applied to the modulator's internal limiter and split into quadrature signal components. Multiplying these quadrature components together with the baseband I and Q components creates a modulated carrier centered on the LO frequency (C). Unfortunately, any unwanted DC components in the baseband I and Q signals will also be multiplied with the LO and generate LO leakage (the arrow in the center of the spectrum). The presence of this LO leakage will degrade the quality of the modulated carrrier's EVM. Because this signal component falls within the desired channel, it cannot be filtered without removing the desired signals.

The problem can be avoided by using an I/Q modulator with low LO leakage (low input offset voltages on the I and Q input ports). If the DAC and the modulator have the same DC-bias level, allowing a DC-coupled connection, it is possible to use the DAC to apply compensating offset voltages to eliminate LO leakage. However, this is only effective if the I/Q modulator's input offset voltages are stable over temperature.

Nonideal quadrature splitting of the LO and/or gain mismatch between the I and Q channels will also degrade EVM (but will not add out-of-channel spurious signals). Like LO leakage, this effect can be reduced by varying the relative amplitudes and phases of the baseband I and Q signals, although such control must also be maintained over temperature.

In a frequency-agile system, the signal chain must be designed so that carrier frequencies can be synthesized over a defined range. For example, a WCDMA base station might be designed to operate anywhere from 1930 to 1990 MHz or 2110 to 2170 MHz. The LO must tune over this range, but the modulator output cannot be filtered inside this range. Thus, post-modulator filtering can at best reduce out-of-band noise rather than in-band noise.

In Fig. 3, once the signal from the modulator has been filtered and subjected to some gain control, it is boosted in amplitude by a power-amplifier (PA) predriver and then a high-power amplifier (HPA) before being transmitted (point E). The amount of amplifier gain

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depends on the output power provided by the modulator. Since the PA gain also increases noise, less gain is better. Ideally, the modulator should provide the highest possible output with the lowest possible noise.

Direct-conversion transmitters are susceptible to an effect known as LO pulling which occurs if some of an HPA's output signal leaks back to the LO and causes phase modulation. The problem is potentially severe when the PA is located close the transceiver PCB, although careful layout and effective grounding can minimize the problem.

Figure 4 shows a block diagram of a superheterodyne transmitter, obviously more complex than the direct-conversion transmitter. The baseband section is similar to the direct-conversion modulator, with a filtered baseband spectrum being driven into an I/Q modulator (points A and B). However, the output of the I/Q modulator is now translated to an IF (C). At this point in the signal chain, the signal can be narrowband filtered with a selective IF filter, such as a surface-acoustic-wave (SAW) filter (point D). This filtering option is the key advantage of the superheterodyne architecture over a direct-conversion approach. Still, the LO leakage that occurs in direct-conversion transmitters can also plague superheterodyne designs, and the IF filter will not help. The superheterodyne approach allows gain control at IF, with typically better performance and lower cost than variable-gain amplifiers (VGAs) at RF.

After the signal has been narrowband filtered, it is translated to the final carrier frequency, requiring a relatively high-frequency LO offset from the final carrier by the IF. The mixing process produces sum and difference components, one of which will fall in-band (E). The operation will also result in some LO leakage and will produce a family of spurious signal products from the intermodulation of LO and IF harmonics. Careful frequency planning is required to ensure that none of these spurious signals falls within the transmission band. There is no chance to filter out spurious components that fall in-band. Also, the IF must be selected high enough so that the LO leakage signal falls well out of band. Following the signal flow in Fig. 4, the signals from the mixer are filtered (point F) and then amplified in a manner similar to the direct-conversion transmitter (point G).

Comparing the two transmitter architectures emphasizes the importance of a high-dynamic-range I/Q modulator for an effective direct-conversion transmitter. **Figure 5** shows a plot of a the spectrum of a single-carrier WCDMA signal spectrum at 2140 MHz synthesized using AD9777, a 16-b dual-DAC (model AD9777) and an 700-to-2700-MHz

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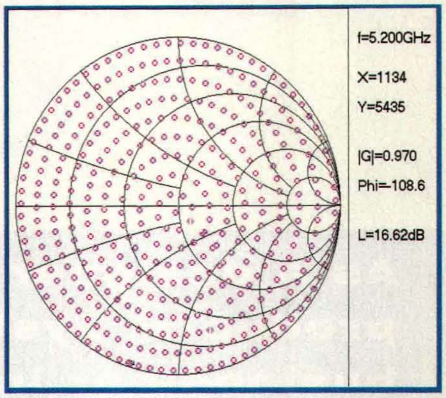

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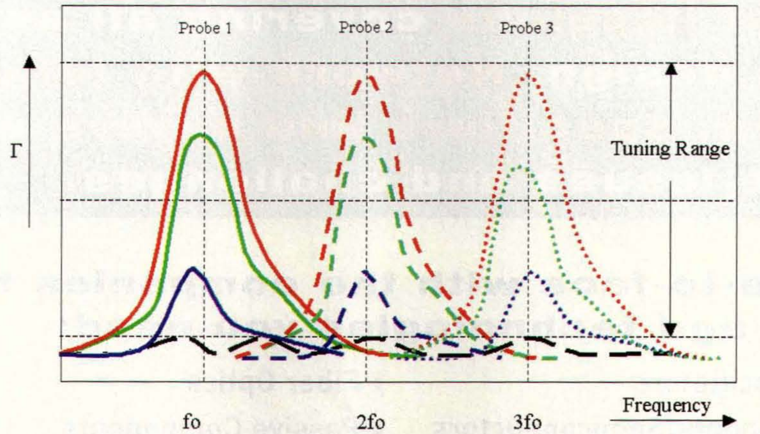

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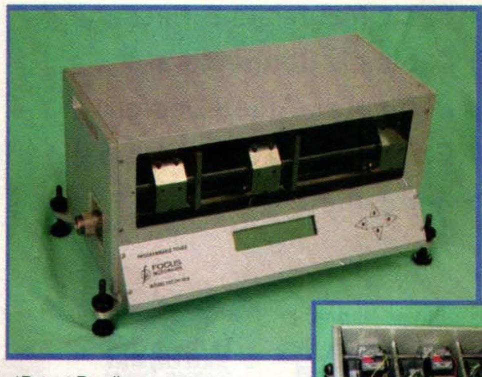

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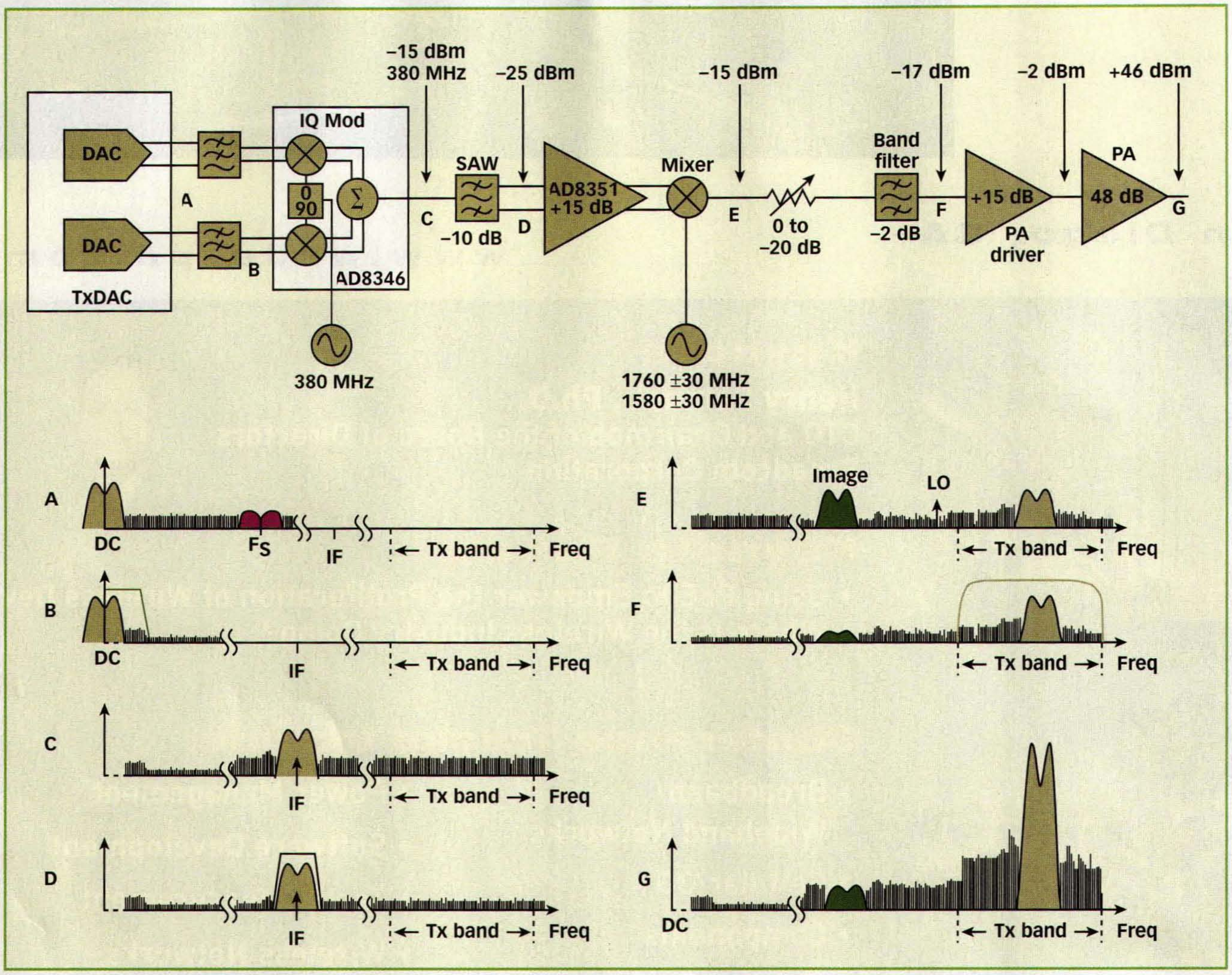
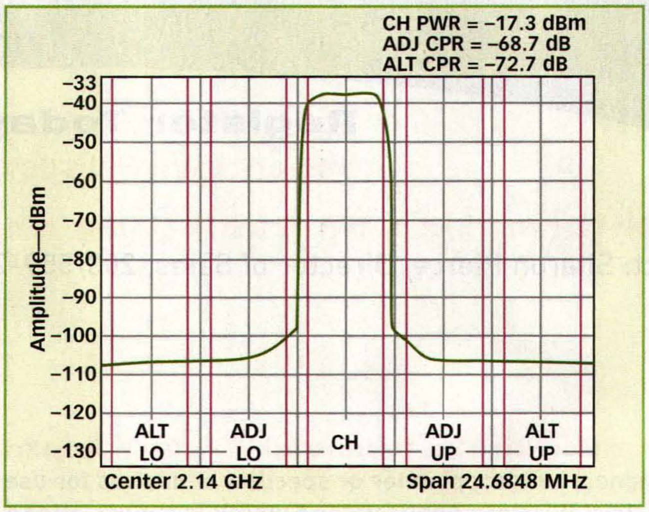


4. A superheterodyne transmitter has a much higher component count than a direct-conversion transmitter, but features an architecture that allows spurious signals to be filtered at IF and RF.

I/Q modulator (model AD8349) with a compression point of +5 dBm and noise floor of –156 dBm/Hz. The plot indicates an ACLR of approximately –69 dBc at a carrier output power of –17 dBm (the measurement is slightly degraded by the noise floor of the spectrum analyzer). The power in the adjacent channels is dominated by spectral leakage from the modulated carrier and not from the device's noise floor. The alternate-channel power ratio is flat across the channel, indicating that it is dominated by noise.



5. The high peak-to-average ratio of a multicode WCDMA carrier demands that the modulator operates well backed off from its compression point in order to meet the ACPR requirements of the 3GPP standard.

Figure 6 shows how the ACLR of a single-carrier WCDMA signal at 1960 MHz and 2140 MHz varies with output power. An ACLR of –68 dBc occurs at a power level of approximately –15 dBm. Above this level, the ACLR degrades because of increasing distortion; below this level, the device's noise floor degrades the ACLR. The noise floor measured 20 MHz from the carrier is relatively flat with channel power, indicating degradation of SNR with decreasing carrier power.

The goal of the transmitter signal-chain designer is to select a modulator output level that provides acceptable ACLR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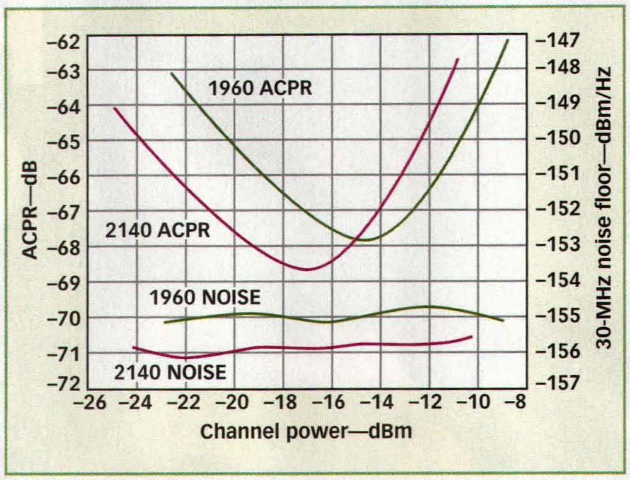
while also satisfying in-band system noise requirements. For example, at 1960 MHz, if the output power level is set at –10 dBm, the ACLR is equal to –64 dBc. Choosing a modulator output power level of –10 dBm calls for 56 dB post-modulator gain for the desired +46 dBm base-station output power. But the modulator's noise will also be boosted by the gain. Measured in a 1-MHz bandwidth, the noise at the antenna is:



6. Modulator ACLR is affected at low power levels by the noise floor while at higher output power levels, distortion dominates. The output power must be set at a level that gives acceptable ACLR and a low enough noise floor.

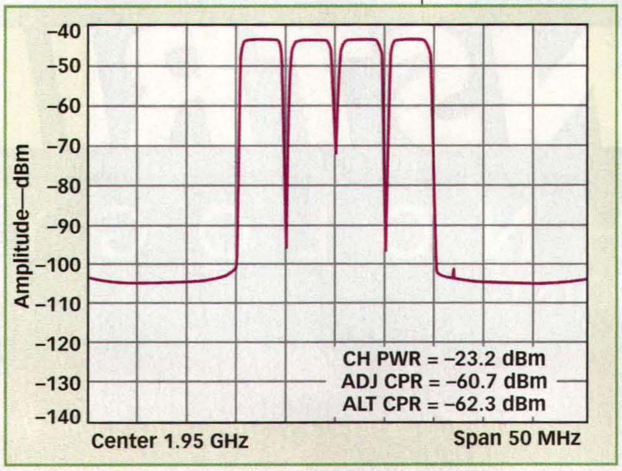
$$\text{Noise (dBm/1 MHz)} = -155\ \text{dBm/Hz} + 10\log_{10}(1\ \text{MHz}) + 56\ \text{dB} = -39\ \text{dBm}$$

which is well within the worst-case requirements of the 3GPP spurious emissions specification of –30 dBm and even suggests that the modulator could be run at a slightly lower output power with improved ACLR.

Figure 7 shows a plot of four WCDMA carriers at 1960 MHz, synthesized by the AD8349. The per-carrier output power must be reduced to maintain the overall output power at a reasonable level. In this case, optimum ACLR of –61 dBc was achieved at a per-carrier power of –23 dBm. In Fig. 7, side-skirts are less apparent suggesting that the ACLR is dominated by the device's noise floor.

If the total output power is chosen to be –17 dBm (i.e., four carriers each at –23 dBm), 63 dB of post-modulator gain will be required to achieve total power of +46 dBm at the antenna. Since the noise floor is –155 dBm/Hz, the noise power at the antenna will be:

$$\text{Noise (dBm/1 MHz)} = -155\ \text{dBm/Hz} + 10\log_{10}(1\ \text{MHz}) + 63\ \text{dB} = -32\ \text{dBm}$$

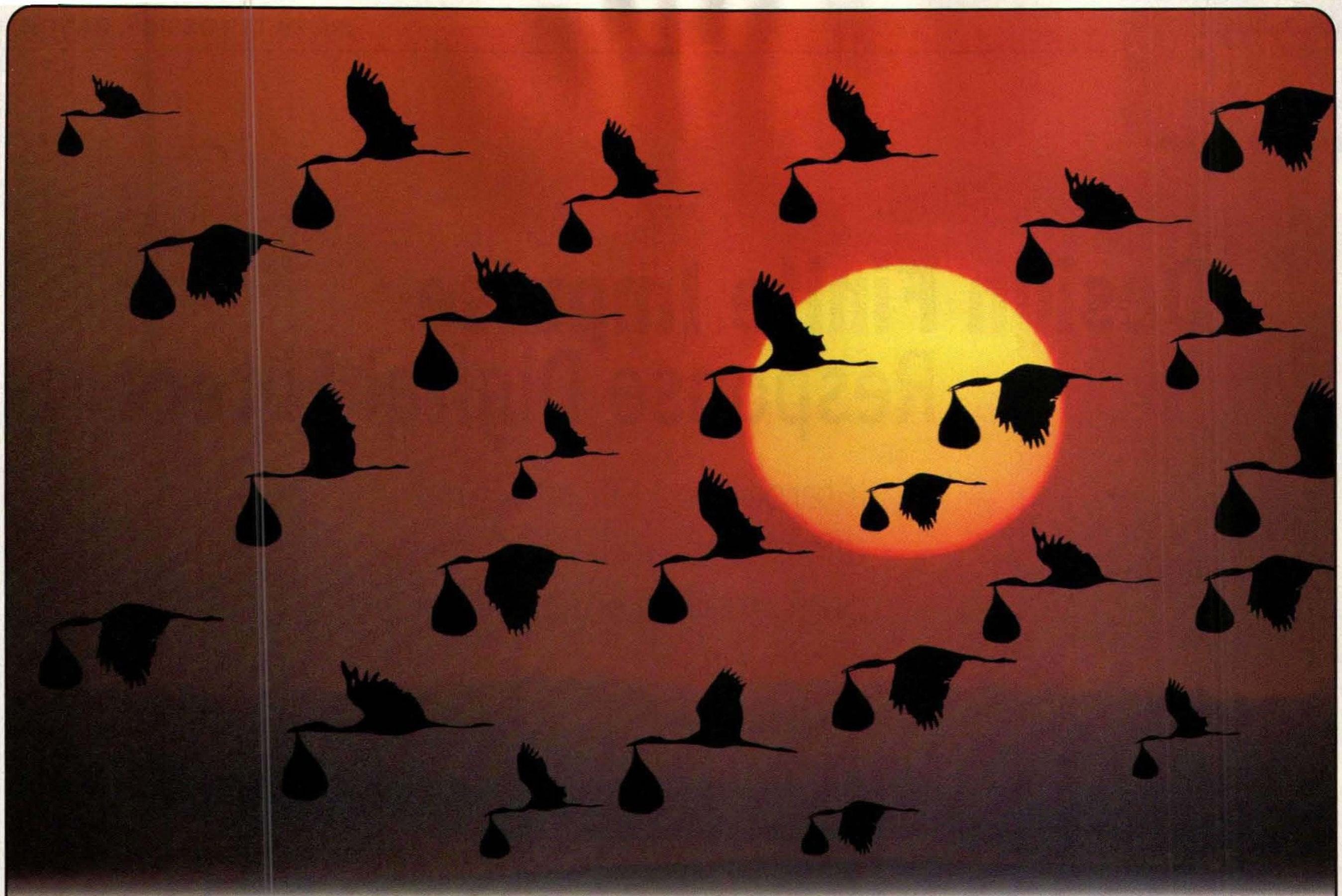


7. To transmit multiple WCDMA carriers, the percarrier power must be reduced. ACLR is now dominated by the modulator's noise floor but is still well below the limits set by the 3GPP standard.

While this noise power level is closer to the –30 dBm limit in the 3GPP standard, it still represents reasonable margin. However, the calculation suggests that it may be prudent to run the modulator at a slightly higher output power and accept degraded ACLR. MRF

REFERENCE

1. Standard 3GPP TS 25.104, Universal Mobile Telecommunications System (UMTS); UTRA (BS) FDD; Radio transmission and reception. Section 6.6.2.2.



Design Finite Impulse Response Digital Filters

Interpolated FIR filters can combine two designs to achieve a demanding set of performance specifications while at the same time conserving computational resources.

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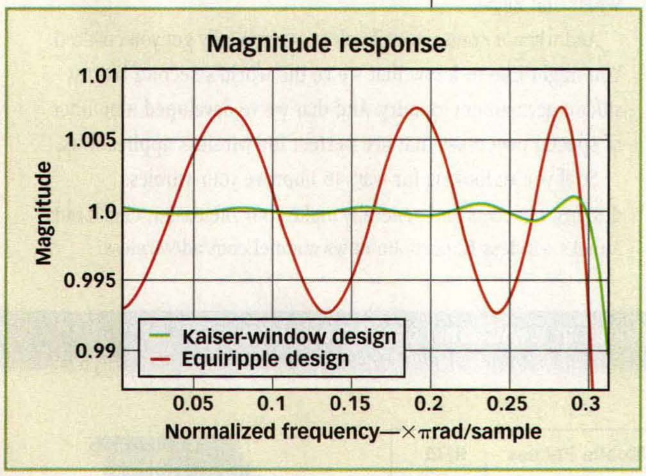
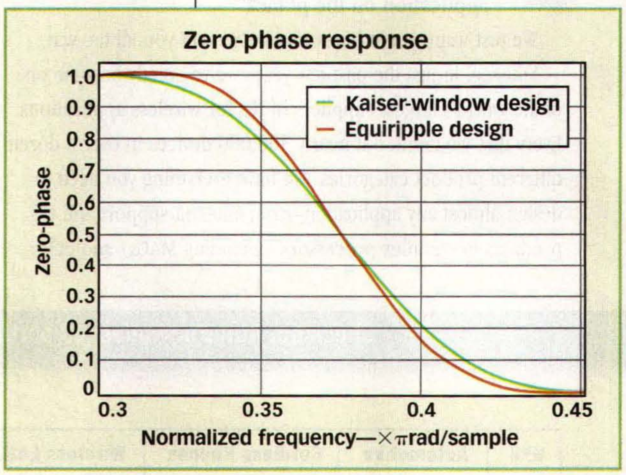
DSP Development Engineer
The MathWorks, Inc., 3 Apple Hill Dr., Natick, MA 01760; (508) 647-7000, FAX: (508) 647-7001, Internet: www.mathworks.com.

Finite-impulse-response (FIR) digital filters enable many modern communications systems. Last month, this four-part article series opened with a review of key filter specifications and how tradeoffs impact final performance and examined several examples of optimal FIR designs, including filters with linear and nonlinear phase responses, and how the MATLAB mathematical software can be used to design such filters. This month, the second part of the series will further the investigation of optimal equiripple FIR filters and introduce some advanced design algorithms for interpolated FIR filters.

Last month, optimal equiripple designs were shown to outperform Kaiser-window designs for the same order and transition width. The differences between these approaches are even more dramatic when the passband ripple and stopband ripple specifications are different, since truncated-and-windowed impulse response methods always give a result with approximately the same passband and stopband peak ripple. Stringent peak-ripple constraints are often satisfied in excess of all other ripple constraints, and often at the



11. These plots show the passband ripple for the Kaiser-window-designed FIR filter and the remez-designed FIR filter. The former exceeds the specification at the expense of an increased number of taps.



12. These response curves compare a Kaiser-window-designed FIR filter and an optimal equiripple FIR filter of the same order and peak ripple values. The latter features reduced transition width.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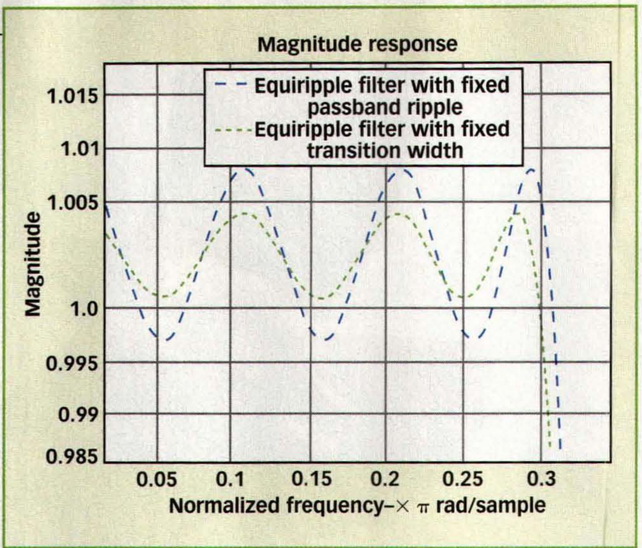


13. Two optimal equiripple FIR filters of 40th order are compared here. Both have the same stopband-edge frequency and minimum stopband attenuation. One is optimized to minimize the transition width while the other is optimized to minimize the passband ripple.

expense of unnecessarily large filter order.

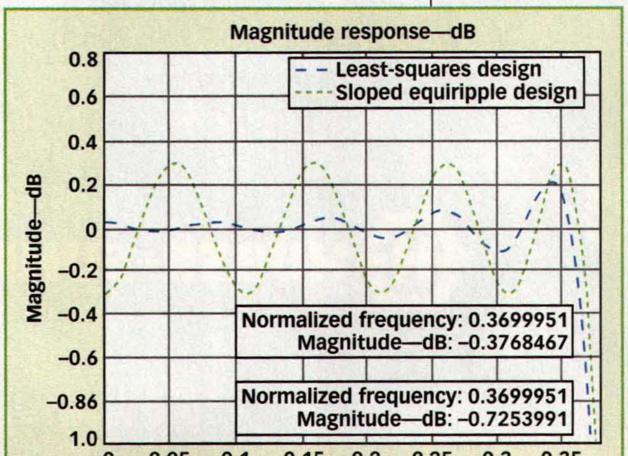
As an example, consider an equiripple design in which both the peak ripples and the transition width are fixed. As shown in Fig. 2, the order of the filter will be dictated by the peak-ripple and transition-width requirements. Using the second set of example specifications, with a cutoff frequency of 0.375π rad/sample, transition width of 0.15π rad/sample, maximum passband ripple of 0.008, and maximum stopband ripple of 0.0009, the "gremez" function can be used to design this filter

```
b = gremez('minorder',[0 .3 .45 1],...
[1 1 0 0],[.008 .0009]);
```

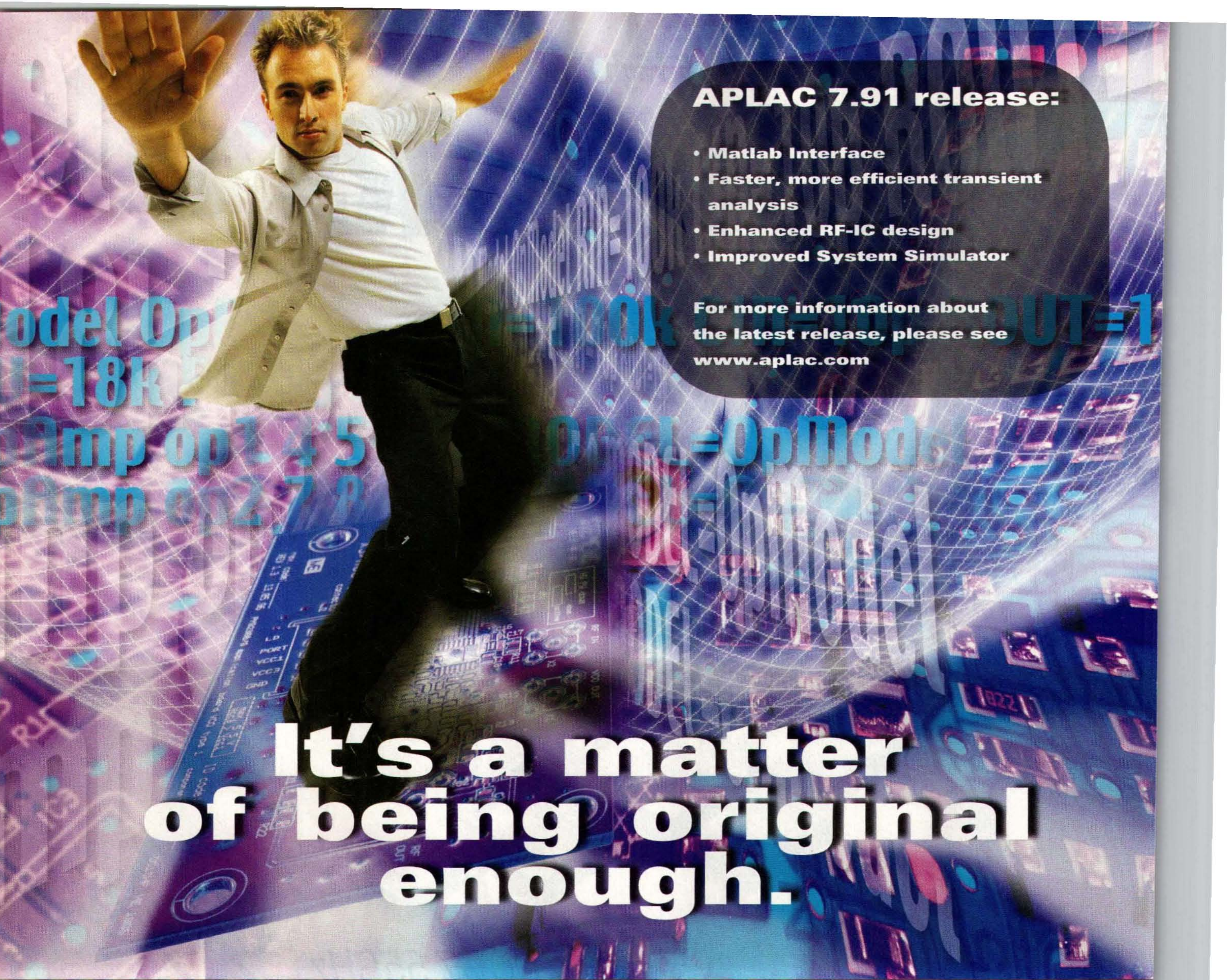
resulting in a 37th-order filter (38 taps). By comparison, a Kaiser-window design requires a 50th-order filter (51 taps) to meet the same specifications. **Figure 11** shows the passband details, revealing that the Kaiser-window design significantly over-satisfies the requirements.

The approach used to design minimum-phase filters with fixed filter order and fixed transition width can be used to design minimum-phase filters with fixed transition width and peak passband/stopband ripple. Rather than obtaining smaller ripples, the benefit is meeting the same transition width and peak passband/stopband ripples with a reduced filter order.

For example, consider a third set of example specifications: a cutoff frequency of 0.13π rad/sample, transition width of 0.02π rad/sample, maximum passband ripple of 0.01, and maximum stopband ripple of 0.001. The minimum order needed to meet such specifications with a linear-phase FIR filter (an optimal equiripple design) is 262. If the linear-phase constraint is relaxed, however, the "gremez" func-



14. This plot offers passband details of a sloped optimal equiripple FIR design and an optimal least-squares FIR design. The equiripple filter has a smaller peak error or smaller transition width depending upon the interpretation.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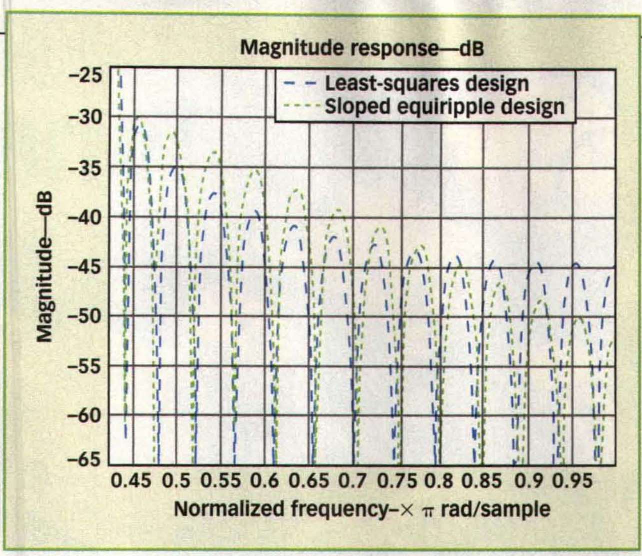
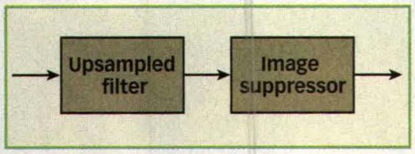


15. This plot shows stopband details for a sloped optimal equiripple FIR design and an optimal least-squares FIR design. The overall error of the equiripple filter approaches that of the least-squares design.

tion can be used to design a minimum-phase FIR filter that meets the specifications set with 216th order:

```
bgm = gremez('minorder', [0 .12 .14 1],...
    [1 1 0 0],[0.01 0.001],'minphase');
```

Examples so far have detailed equiripple designs with fixed transition width and fixed order and designs with fixed transition width and fixed peak-ripple values. MATLAB's Filter Design Toolbox also provides algorithms for designs with fixed peak-ripple values and fixed filter order.[6] This gives maximum flexibility in utilizing the degrees of freedom available to design an FIR filter.

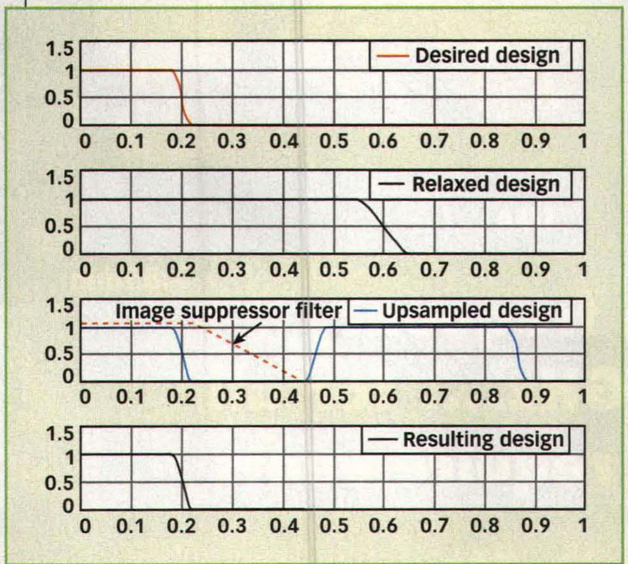


16. In an IFIR implementation, an upsampled filter is cascaded with an image suppressor filter to attain an overall design with a reduced computational cost.

Compared to Kaiser-window designs, fixing the transition width and filter-order results in an optimal equiripple design with smaller peak ripple values, while fixing the transition width and peak ripple values results in a filter with less number of taps. Fixing the filter order and the peak ripple values should result in a smaller transition width, which can be verified by using the firceqrip function:

```
bc = firceqrip(50, 0.375, [0.008 0.0009]);
```

Figure 12 offers a comparison of this design with a Kaiser-window filter. For



17. The IFIR approach involves the use of two filters to attain stringent transition width specifications with reduced total multiplier count when compared to a single filter design.

the new filter, the transition width has been reduced from 0.15π to approximately 0.11π.

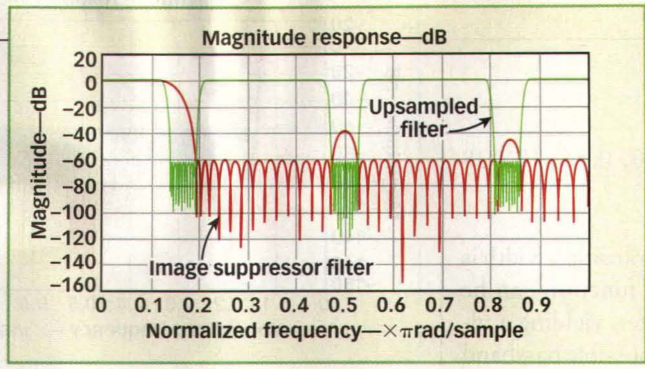
If linear phase is not a requirement, a minimum-phase filter can be designed that is superior in some sense to a comparable linear-phase filter. For the same filter order and peak-ripple value, a minimum-phase design results in a smaller transition width than a linear-phase design. For example, compared to the 50th-order linear-phase design "bc" above, the "bcm" design that follows has a noticeably smaller transition width:

bcm = firceqrip(50, 0.375, [0.008 0.0009], 'min');

Further equiripple design options are available in the Filter Design Toolbox. Notable examples include the constrained-band design, where the filter order can be fixed along with the peak ripple and the beginning/end of a given band (passband or stopband), and the sloped stopband design, where the stopband is no longer equiripple, but rather has a predetermined slope.

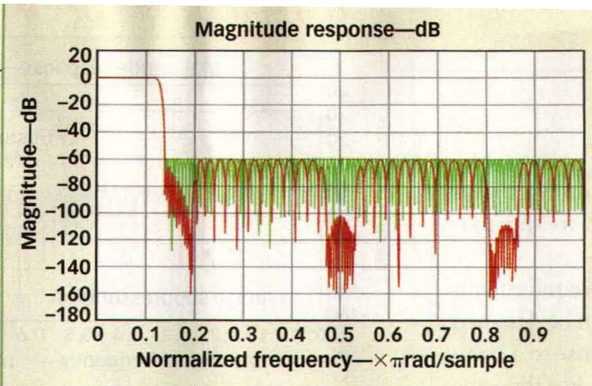
When designing lowpass filters for decimation, it is sometimes necessary to guarantee that the filter stopband begins at a specific frequency value and that the filter provides a given minimum stopband attenuation. If the filter order is fixed, for example when using specialized hardware, there are two alternatives available in the Filter Design Toolbox for optimal equiripple designs. One possibility is to fix the transition width, the other is to fix the passband ripple.

As an example, using the second set of design specifications calls for a stopband that extends from 0.45π to π and provides minimum stopband attenuation of approximately 60 dB. Assuming that an example filter order of 40 (41 taps) is available, the "fircequip" function can be used to design this filter if the passband ripple is also fixed to 0.008. The function will yield a filter with the smallest possible transition width for any linear-phase FIR filter of that order that meets the given specifications:



18. This plot shows the magnitude response of the upsampled filter and the image suppressor filter in an IFIR design.

bc = firceqrip(40, 0.45, [0.008 0.0009],'stopedge');



19. This plot compares the overall magnitude response of an IFIR design and a conventional equiripple design. The IFIR implementation requires 127 multipliers while the equiripple design requires 263 multipliers.

In contrast, if the transition width is fixed, the "gremez" function can be used to design the filter, yielding a filter with the smallest possible passband ripple for any linear-phase FIR filter of that order that meets the second set of specifications:

bg = gremez(40, [0 .3 .45 1], [1 1 0 0],...
[1 0.0009], {'w', 'c'});

Figure 13 compares the passbands of the two filters. Both designs meet the specifications since the order (40) is larger than the minimum order required (37) for an equiripple linear-phase filter to meet the specifications. The filters differ in how they "use" the extra number of taps to better approximate the ideal lowpass filter.

An alternative to using least-squares designs is to design optimal equiripple filters and allowing for a slope in the stopband of the filter. This has the advantage (over least-squares designs) that the passband can remain equiripple, thus minimizing the input signal fluctuations in that region. While it is possible to achieve sloped stopbands with "remez" or "gremez" methods by using the weights, the "firceqrip" function provides the best control and easiest way to do this (at the expense of not having full control over the transition width). With the "firceqrip" function, it is possible to specify the desired slope (in dB per frequency unit) for the stopband.

For example, the design

bf = firceqrip(42, 0.4346, [0.035], [0.03],...
'slope', 40, 'stopedge');

results in stopband energy of approximately 3.9771e-005, which is not much larger than the least-squares design of Part 1 (Eq. C), while having a smaller transition width (or peak passband ripple, depending upon the interpretation). **Figure 14** shows the passband

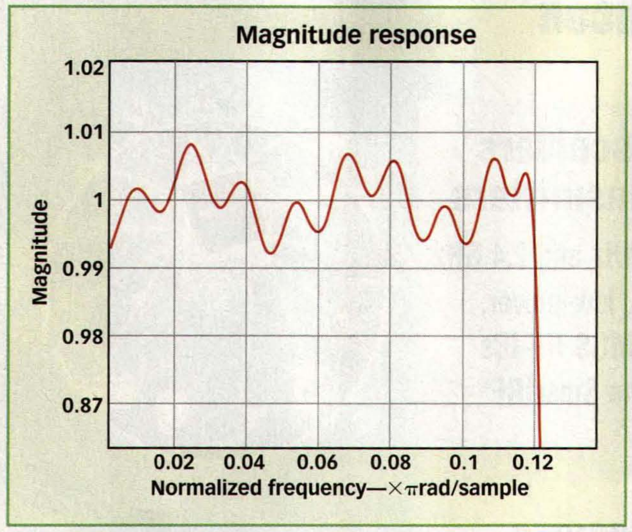
details (in dB) of the least-squares sloped equiripple designs, while **Fig. 15** offers the stopband details (also in dB).

Interpolated FIR Filters

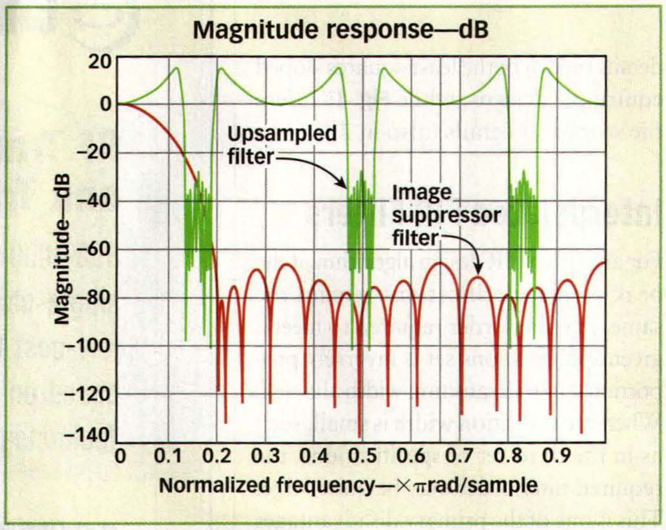
For any given FIR design algorithm, if the peak ripple specifications remain the same, the filter order required to meet a given specifications set is inversely proportional to the transition width allowed. When the transition width is small, such as in the third set of specifications, the required filter order may be quite large. This is one of the primary disadvantages of FIR filters. It has already been shown that relaxing the linear-phase requirement results in a significant savings in the number of filter coefficients.

The so-called *interpolated* FIR (IFIR) approach[9-11] yields linear-phase FIR filters that can meet the given specifications with a reduced number of multipliers. Quite simply, since the length of the filter grows as the transition width shrinks, the filter is not being designed for a given (small) transition width. Rather, the filter is designed for a multiple L of the transition width. The filter will have a significantly smaller length than a direct design for the original (small) transition width. The impulse response of this smaller filter is then upsampled by a factor equal to the multiple of L. Upsampling will cause the designed filter to compress, meeting the original specifications without introducing extra multipliers (it only introduces zeros, resulting in a larger delay). The penalty for this action is the appearance of spectral replicas of the desired filter response within the Nyquist interval. These replicas must be removed by a second filter (called the interpolation filter or image suppressor filter) that is cascaded with the original to obtain the desired overall response. Although this extra filter introduces additional multipliers, it is possible in many cases to still have overall computational savings relative to conventional designs **(Fig. 16)**.

As an example, consider a design with upsampling factor of 3 **(Fig. 17)**. The "relaxed" design is approximately of one third the length of the desired design, if the latter were to be designed directly. The



20. This closeup of the IFIR passband shows the chaotic behavior of the ripple.



21. This plot compares the magnitude responses of the upsampled filter and the image suppressor filter in an optimized IFIR design.

upsampled design has the same transition width as the desired design. All that is left is to remove the spectral replica introduced by upsampling, which is the function of the image suppressor filter.

To show the savings in computation, consider the third set of design specifications. The number of multipliers required for a single linear-phase design was 263. An IFIR design can attain the same specifications with 127 multipliers when using an upsampling factor of 6:

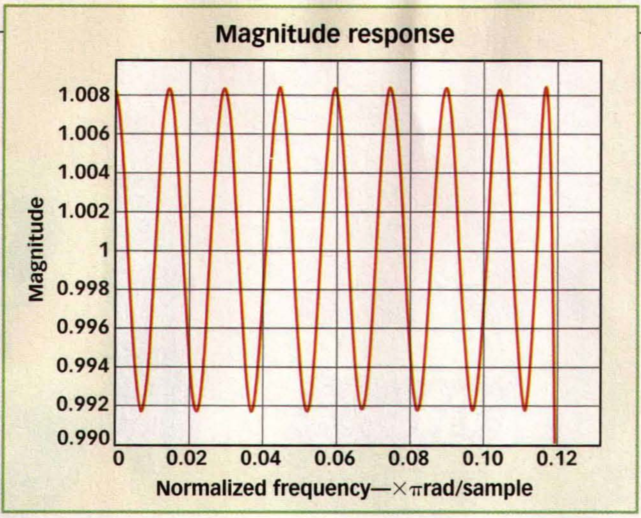
[bup,bimg] = ifir(6, 'low', [.12 .14], [.01 .001]);

Figure 18 shows the response of the upsampled filter and the image suppressor filter, while **Fig. 19** shows the overall (composite) response compared to a single linear-phase equiripple design.

A drawback in the IFIR design is that the passband ripples of the two filters are combined in a disorderly fashion. In the worst-case scenario, they can add up, requiring the design to ensure that the sum of the two peak passband ripples does not exceed the original set of specifications. A closeup of the passband of the previous IFIR example filter **(Fig. 20)** shows the chaotic behavior of the ripple (although still meeting the specification). Further optimized designs,[2,12] attain a much cleaner passband behavior by jointly optimizing the design of the two filters. This results in a filter that can meet the specifications set with an even further reduction in the number of multipliers. The savings are especially significant for the image-suppressor filter, which is greatly simplified by this joint optimization.

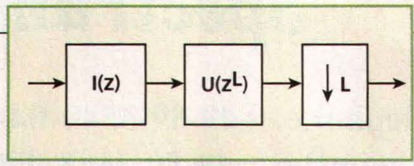
Using joint optimization, the third set of design specifications can be met with only 74 multipliers and an upsampling factor of 6. The filter can be designed using the 'adv' flag in the "ifir" function. The manner in which

the two filters work together is best described by looking at their magnitude responses (**Fig. 21**). By precompensating for a severe "droop" in the image suppressor filter, a flat passband can be achieved with dramatic savings in the number of multipliers required for the image suppressor filter. Out of the 74 multipliers required, 29 are for the image suppressor filter and 45 for the upsampled filter. By contrast, in the previous IFIR design, 78 of the 127 multipliers correspond to the image suppressor filter, while 49 correspond to the upsampled filter. The passband details of the overall design show a well-behaved equiripple response, hinting at a much better optimized design (**Fig. 22**).

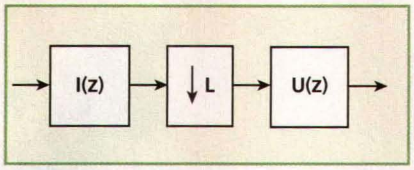


22. This plot shows the passband response of an optimized IFIR design with well-behaved equiripple response.

When designing an IFIR filter, the upsampling factor L must be such that the (normalized) stopband-edge frequency ω_s satisfies the condition $L\omega_s < \pi$. This implies that the bandwidth of the output signal would be reduced by a factor of L. From a computational perspective, it is convenient to reduce the sampling frequency of the filtered signal, since at that point the Nyquist criterion is unnecessarily oversatisfied. Subsequent processing of the filtered signal without reducing its sampling rate would results in unnecessary (and expensive) redundant processing of information. The filtered signal should be downsampled by a factor of L to match the reduction in bandwidth due to filtering. If I(z) is the image suppressor filter and $U(z^L)$ is the upsampled filter, the cascade of the filters can be shown by **Fig. 23**. Using the Noble identities, it is possible to "commute" the downsampler and $U(z^L)$ to obtain the implementation of **Fig. 24**. The combination of I(z) and the downsampler form a decimator, which can be implemented efficiently in polyphase form.



23. This simple block diagram portrays the cascade of an IFIR filter with a downsampler.



24. This implementation is achieved by interchanging the downsampler and the upsampled filter by means of the Noble identities.

Next month, this four-part FIR filter design series will continue with an examination of interpolation filter design, notably for band-limited interpolation filters. The discussion will include details on designing Nyquist FIR filters, halfband FIR filters, and two-channel FIR filter banks. MRF

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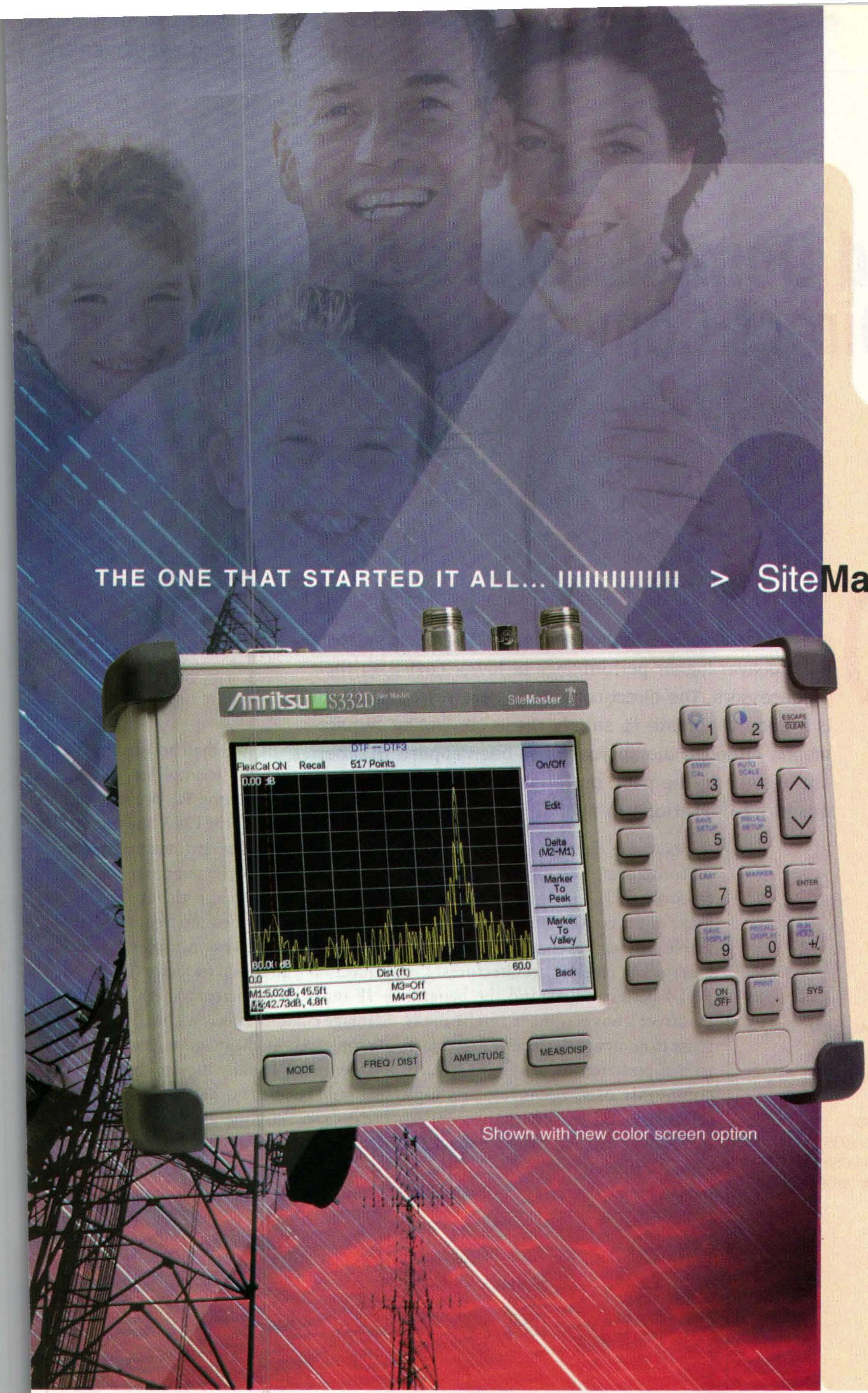
THE ONE THAT STARTED IT ALL... > SiteMaster
Anritsu S332D
SiteMaster
On/Off
Edit
Delta (M2-M1)
Marker To Peak
Marker To Valley
Back
MODE
FREQ / DIST
AMPLITUDE
MEAS/DISP
Shown with new color screen option

Quad Demodulators Arm Direct-Conversion Receivers

With the help of wide-dynamic-range components, direct-conversion architectures offer significant advantages in simplicity and cost compared to superheterodyne approaches.

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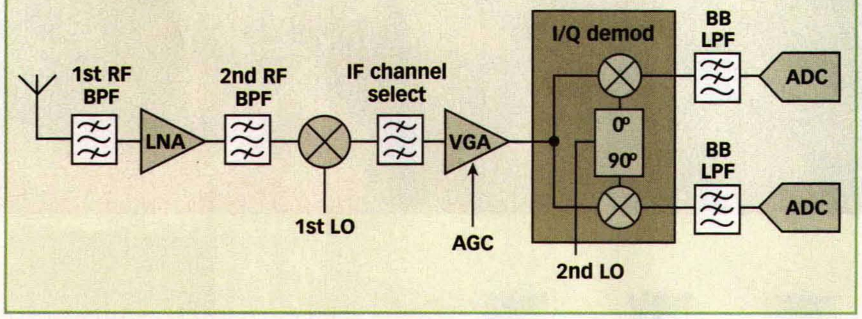
Base-station receivers for next-generation wireless systems must deliver higher performance at lower cost than their predecessors. The direct-conversion receiver architecture is a good candidate to satisfy these conflicting requirements. Although the approach has been applied to different designs in the past, performance has been compromised by limitations in available hardware, including demodulators. Fortunately, the improved performance of commercial integrated-circuit (IC) quadrature demodulators make direct-conversion receiver designs viable alternatives to traditional superheterodyne receiver architectures.

To better understand the benefits of direct conversion, it might make sense to compare the receiver approach to a superheterodyne system **(Fig. 1)**, commonly used because of its high selectivity and sensitivity. In a superheterodyne receiver, the received RF signal is filtered by the first RF preselection filter to remove out-of-band signals, and then boosted by the low-noise amplifier (LNA). The second RF preselection filter at the LNA output provides additional filtering to attenuate undesirable signals at the image frequency. The resulting signal is then translated to a lower, intermediate frequency (IF) by a downconversion mixer in conjunction with a local oscillator (LO). The IF must be sufficiently high that the image channel falls is within the filter's stopband. Such image-rejection considerations usually dictate that the IF should be on the order of 10 percent of the carrier frequency. The RF preselection filters serve to remove out-of-band energy and reject the image-band signals. Since a superheterodyne receiver



1. This block diagram shows a simplified superheterodyne receiver.

LT5515 and LT5516 performance highlights

	LT5516 @900 MHz	LT5515 @1900 MHz
RF freq. range (MHz)	800 to 1500	1500 to 2500
BB freq. Range (MHz)	DC to 260	DC to 260
Conversion gain (dB)	4	–0.7
NF (dB)	12.8	16.8
IIP3 (dBm)	21.5	20
IIP2 (dBm)	52	51
LO power (dBm)	–5	–5
I/Q gain mismatch (dB)	0.2	0.3
I/Q phase mismatch	1°	1°
LO leakage at RF input (dBm)	–65	–46
Output DC offset voltage @P_{LO} = –5 dBm	1 mV	4 mV
Offset voltage vs. temp.	20 µV/°C	30 µV/°C

performs the channel-filtering function in the IF and baseband stages, aggressive dynamic-range requirements are imposed on the components in these stages.

For superheterodyne receivers in base stations, a fixed-gain LNA is typically used for initial amplification of the received signals. The entire passband, including noise, is translated in frequency to a fixed IF. For the frequency downconversion, a passive (diode) mixer is most often utilized in order to meet the dynamic-range requirements of high linearity and low noise, although high LO power (greater than +10 dBm) is needed to drive such a mixer. Poor LO-to-IF isolation, typical of passive mixers, complicates the LO filtering in the receiver's IF section. At the IF output of the mixer, the desired signal channel always resides at the center of the IF channel-select filter, which is used to remove unwanted adjacent or alternate channels.

Following the IF channel-select filter, the desired channel is boosted by a variable-gain amplifier (VGA) and then demodulated to baseband for further signal processing. The high-quality-factor (Q) IF channel-select filter passes desired signals and rejects unwanted signals, including larger-amplitude alternate-channel signals. Unfortunately, such selective filters are expensive and add undue cost to the superheterodyne receiver. Moreover, high-Q filters are typically accompanied by high insertion loss requiring additional gain in the LNA and mixer stages to offset the filter loss and lower noise figure in the VGA.

Since the LNA gain is fixed in the base-station receiver, the mixer in particular must achieve very high linearity to meet the system's strict dynamic-range requirements. Moreover, the IF channel-select filter has a frequency response precisely tuned to the required channel bandwidth. The inflexibility of the IF channel-select filter limits the receiver hardware to a single RF standard. Because of the proliferation of standards for wireless communications, however, new receiver systems must support a variety of different standards seamlessly and cost-effectively, with limited cost budget for any one standard.

The direct-conversion receiver architecture can achieve the goals of a superheterodyne design, but with considerably less complexity **(Fig. 2)**. In this system, the received signals are amplified with a fixed-gain LNA after the first RF preselection filter. Subsequently, the RF signals are directly downconverted to in-phase (I) and quadrature (Q) baseband signals without an intervening IF stage. The requirements for the second RF preselection filter are less stringent than for the first, because there is no image channel. In practice, an inexpensive RF bandpass filter can prevent strong out-of-band signals from overloading the I/Q demodulator. [Without this filter, strong out-of-band signals may result in both in-band second-order and third-order intermodulation products, causing intersymbol interference (ISI)]. After the RF signals are demodulated to baseband, individual channel selection is performed using a baseband channel-select filter. The baseband filter is more compact and less expensive than the superheterodyne receiver's IF channel-select filter. In addition, the baseband chan-

nel-select filter can be designed with variable bandwidth, facilitating multi-mode or multi-standard operations.

Although baseband channel-select filters offer a great deal of flexibility, the composite baseband signals contain all of the adjacent-channel blocking signals that are normally filtered before they reach the I/Q demodulator (see Fig. 1). As a result, the direct-conversion-receiver's I/Q demodulator must provide a dynamic range as wide as 80 dB.

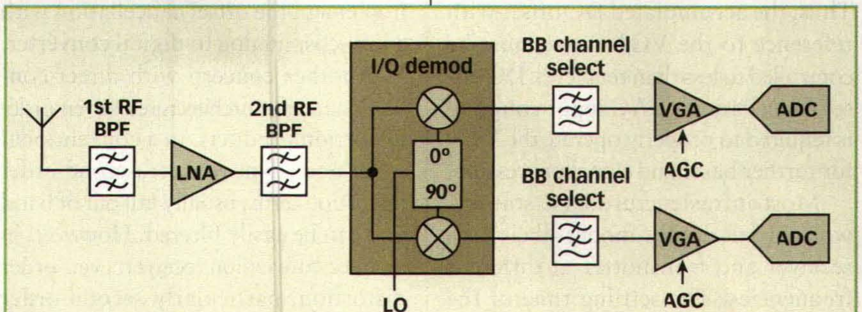
Fortunately, the LT5515 and LT5516 I/Q demodulators from Linear Technology (Milpitas, CA) are among a handful of commercial products that provide this kind of performance. The two ICs each integrate the functionality of an RF signal splitter, a precision quadrature LO signal splitter and two high linearity downconverting mixers. The chips directly downconvert an RF signal to baseband, and demodulate the in-phase (I) and quadrature (Q) signal components. The devices' matched I and Q channels ensure precise gain and phase matching, so that significantly less calibration is required. The LT5515 operates from 1.5 to 2.5 GHz while the LT5516 handles an RF input-signal range from 0.8 to 1.5 GHz. The chips also integrate single-pole, lowpass filters with 260-MHz bandwidth on each of the I and Q channels **(see table).**

Both direct-conversion quadrature modulators achieve impressive amplitude and phase balance between signal channels. The gain levels between I and Q arms of the LT5515, for example, are maintained within 0.3 dB of each other, while the phase balance is within 1 deg. For the lower-frequency LT5516 quadrature demodulator, the gain matching between the I and Q channels is within 0.2 dB while the phase matching is within 1 deg. or less. The devices are rated for RF and LO differential voltages of ±2 V (an equivalent level of +10 dBm) and maximum power-supply voltage of +5.5 VDC. They are rated for operating temperatures from –40 to +85°C and are supplied in 16-lead plastic QFN packages with exposed leads; the square packages measure just 4 mm on a side.

The efficient demodulators provide a shutdown mode in which only 20 µm current is consumed. The turn-off and turn-on times for the shutdown mode are typically 120 and 650 ns, respectively.

The LT5515 and LT5516 demodulators are ideal for receivers requiring good linearity and wide dynamic range, such as wireless base stations (for GSM, CDMA, WCDMA, etc.) and wireless infrastructure equipment, as well as instrumentation applications. Direct-conversion receiver ICs such as the quadrature demodulators eliminate the need for additional IF stages and relax the demands on high-frequency filters, especially by eliminating the IF channel-select filter. With their +20 dBm input third-order intercept (IIP3) and +50 dBm input second-order intercept (IIP2), the quadrature demodulators meet the strict dynamic-range requirements of base-station receivers.

One concern with direct-conversion receiver architectures is spurious LO leakage. This problem arises when a small amount of LO energy is coupled to the I/Q demodulator input, either from the antenna or by means of another path. The LO leakage can mix with



2. This block diagram represents a simplified version of a direct-conversion receiver.

LO itself to generate DC offset. Depending upon the LO leakage path, the carrier feedthrough may superimpose large, possibly time-varying DC errors on the desired baseband signals. In the basestation infrastructure, however, because the receiver systems are typically stationary, the DC offset caused by LO self-mixing is likely static, rather than time varying. Because the LT5515 and LT5516 employ active rather than passive mixers, only –5 dBm LO power level is required rather than the +10 dBm typically needed with passive mixers. Thanks to good isolation between the LO and RF ports, the LO leakage is minimized to a mere –46 dBm for the LT5515 and –65 dBm for the LT5516. Consequently, only a few millivolts of static DC offset may result from the LO self-mixing.

Another concern of the direct-conversion approach is DC offsets caused by device mismatches. Mismatch-induced DC offsets can originate from the quadrature demodulator and/or the VGA. DC offsets at the quadrature demodulator's outputs will not in themselves cause receiver malfunctions or performance degradation. However, due to the limited VGA voltage headroom, a few millivolts of DC offset may be enough to significantly reduce the signal swing or possibly saturate the VGA when it operates in high-gain mode with the gain as high as 60 dB, thus degrading the receiver's effective dynamic range. To handle a large blocking signal, the LNA gain is usually limited to the 20-dB range, so that the desired signal level reaching the mixer under weak-signal conditions may be on the order of a few hundred microvolts. Thus, the accumulated DC offset with reference to the VGA input must be controlled to less than that level. DC offset cancellation or AC input coupling is required to properly operate the VGA for further baseband signal processing.

Most infrastructure base stations work in full-duplex mode, albeit with receiver and transmitter at different frequencies. The settling time of the DC voltages is less of a concern in this type of receiver system. In many modern wireless receiver systems, the baseband signals contain little low-frequency information. This allows the I- and Q-channel outputs of the LT5515 and LT5516 demodulators to be AC-coupled to the baseband filters or VGA through a blocking capacitor, effectively eliminating DC offsets. Since each of the I-channel and Q-channel outputs of the LT5515/LT5516 is internally connected to the supply voltage through a 60-Ω resistor, the resulting output highpass filter's –3-dB rolloff frequency is defined by the RC constant of the blocking capacitor and the output resistive load R_{load}, for R_{load} sufficiently large (much greater than 60 Ω).

When DC coupling of the LT5515/LT5516 to the baseband circuits is required, a digital offset removal method can be employed at the baseband VGA inputs. The DC offsets may be estimated and removed using the baseband processor at each VGA setting. Although the DC offset will not impact the RF performance of the receiver, it must be cancelled in order for the VGA to operate properly. The spectrum loss around DC can be as low as a few Hertz. For a half duplex system, the DC offsets can be separated using an adaptive approach combining carrier recovery, symbol timing recovery, automatic gain control and data detection in the baseband. Typically, in the receiver system, the preamble in the frame structure has a known DC content that allows adaptive, frame-by-frame DC offset removal. With the LO running at –5 dBm, the output DC offsets of LT5516 and LT5515 are as low as 1 mV and 4 mV, respectively. These low offset voltages allow the receiver to implement the offset cancellation with a low-cost analog to digital converter.

Another concern with direct-conversion receiver architectures is even-order distortion products. In a conventional superheterodyne receiver, second-order distortion terms usually fall out of band and can be easily filtered. However, in a direct-conversion receiver, even-order distortion, particularly second-order products, will cause in-band interference. For example, when two strong interferers

with frequency spacing close to the channel bandwidth are present at the input of the quadrature demodulator, the second-order nonlinearity of the demodulator will produce a low-frequency intermodulation product. This distortion product falls in the baseband spectrum and cannot be filtered out in the subsequent baseband signal processing. Consequently, excellent IIP2 is a prerequisite for good performance in a direct-conversion receiver. The presence of mismatches in the mixers of the demodulator and LO signal paths may result in in-band second-order intermodulation products. The second-order harmonic of the input RF signals (from second-order distortion of the RF amplifier) may also be mixed with the second harmonic of the LO signal to produce a similar effect. The high IIP2 of the LT5515 and LT5516 (+51 and +52 dBm, respectively), therefore, are important to prevent even-order intermodulation from corrupting the baseband signals. This performance can be further enhanced by properly filtering the unwanted high-frequency mixing products at the I and Q outputs. This effectively prevents the unwanted mixing products from coupling back to the demodulator to generate in-band second-order intermodulation. A convenient approach is to terminate each output with a shunt capacitor. The capacitor value can be optimized depending upon the operating frequency and the specific printed-circuit-board (PCB) layout.

The design of high-performance direct-conversion receiver systems is at the leading edge of modern base-station receiver development. Although direct-conversion receiver approaches have been studied for decades, only recently have available high-performance components made the direct-conversion architecture practical for a wide range of wireless applications. MRF

Mobile Disruption: The Technologies and Applications Driving the Mobile Internet

JEFFREY L. FUNK

INTERNET ACCESS has become such an essential tool for business and research that most engineers now rely upon the Web for product data sheets, white papers, and other application information. Mobile Internet access simply allows engineers and others to carry that powerful research tool with them at all times. In *Mobile Disruption: The Technologies and Applications Driving the Mobile Internet*, Jeffrey Funk provides an overview of the technologies that have fueled the mobile Internet market as well as a guide to past, present, and future business opportunities based on mobile Internet access.

Funk notes that the growth of mobile access to the Internet will free people from relying on a wide range of devices and possessions currently in use, such as watches, Personal Digital Assistants (PDAs), and portable game units, to be replaced by all of these functions on a single device, such as a multifunction mobile telephone. He points to the trend in Japan, where the cellular telephone has even been accused of being responsible for weakened sales of men's and women's watches. He calls mobile Internet access a disruptive technology since it will improve some aspects of lifestyle while reducing others. The nature of a disruptive technology is to cause a new set of customers to be the first users of the technology. These may be entirely new customers than those using the older technology, or they may simply be among those using the older technology and willing to try a new approach. Funk cites several examples of disruptive technologies, including the move from tube to transistor radios and the move from minicomputers to personal computers. In the case of the former, the radios were smaller and less expensive, at the cost of poorer sound and overall performance. In the case of the latter, the newer computers were smaller and less expensive, but with considerably less processing power. The book highlights key technology trends pushing the growth of mobile Internet access, the power of marketing programs to boost sales of mobile Internet access, and the appeal of mobile on-line shopping capabilities.

Funk, who is a professor of business at Hitotsubashi University in Japan, has studied the business dynamics of the mobile telephone industry for more than 10 years. He has served as a consultant to variety of firms, including NTT, DoCoMo, and Nokia. (2004, 211 pp., hardcover, ISBN: 0-471-51122-6, $54.95.) **John Wiley & Sons, Inc., 111 River St., Hoboken, NJ 07030; (201) 748-6000, FAX: (201) 748-6088, e-mail: StaSmith@wiley.com, Internet: www.wiley.com.**

Plastic Packages Take On High-Power Devices

Advances in over-molded plastic packaging technology now allow developers of high-power RF transistors to encapsulate their devices in reliable housings that rival the performance of ceramics.

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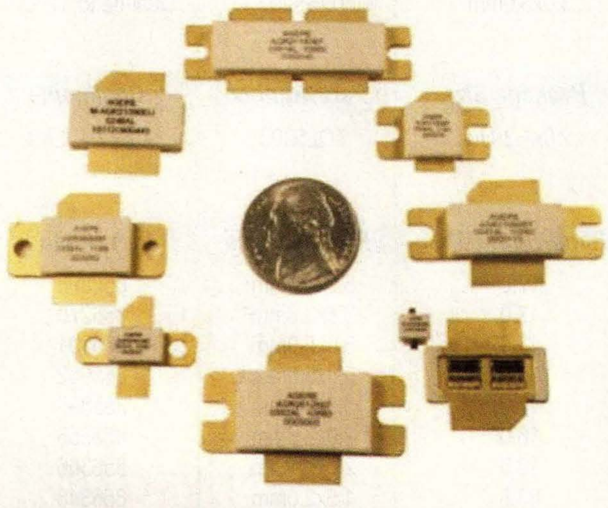
Packaging is critical to achieving maximum performance from RF power transistors. Since RF power transistors are among the most expensive components in a power amplifier (PA), and the PA is the most expensive component in a cellular base station, there is obvious motivation to reduce the cost of the transistor without sacrificing performance. The answer lies with over-molded plastic packaging technology, which is well accepted for other power integrated-circuit (IC) applications but only recently has improved sufficiently to serve the needs of RF power transistor developers. The technology provides the needed technical performance at costs roughly one order of magnitude less than the existing approach.

Innovations that drive the price/performance of RF power semiconductors have enormous potential to impact the future of 2.5G and 3G wireless networks **(Fig. 2)**. High-power RF transistors have traditionally been housed in leaded ceramic packages. Within a base station, power transistors sit on printed-circuit boards (PCBs) that slide into a cellular base station in much the same manner as line cards in telecommunications central-office equipment. A typical cellular/wireless base station has about eight to ten PAs. Power transistors are the largest cost item in the PA and therefore are a very significant contributor to the total cost of all base stations. In addition, roughly 30 percent of the problems with base stations are related to PAs; hence, their reliability is critical to the successful operation of



1. Ceramic power-transistor packages such as these can amount to about one-half the cost of the device.

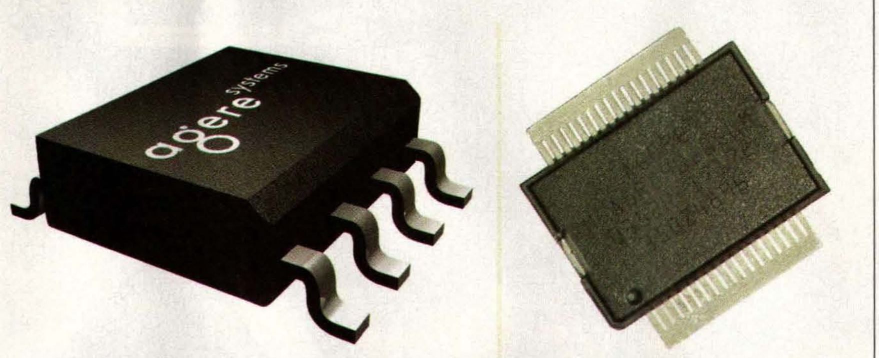
wireless networks.

Because of the performance and reliability demands on RF power transistors, they have traditionally been housed in packages that combine a thermally and electrically conductive metal base with a ceramic ring to isolate the input and output leads. The base is made of a copper-tungsten alloy and is covered with metals to allow attachment to the ceramic ring by means of a high-temperature brazing process. Due to the ceramic ring, this first-generation solution is known as a ceramic package. Additionally, the package base is gold plated to allow the die to be attached by means of a second high-temperature process. For its only form of environmental protection, the package is capped with a ceramic lid that is glued to the ceramic ring and the input and output leads.

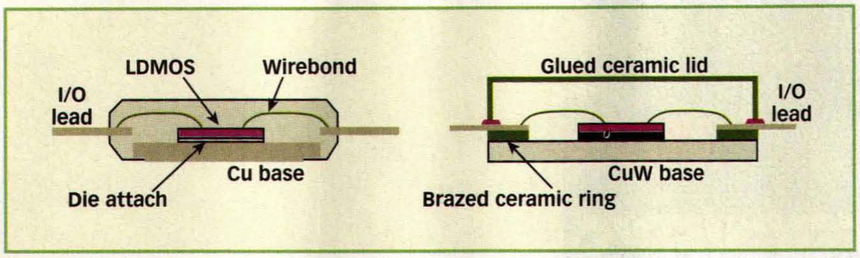
With the ceramic approach, the packaging represents about one-half the total cost of a finished power transistor product **(Fig. 1)**. Of course, for an RF transistor, the packaging not only protects the die, it also provides electrical connections and a thermal path for excess heat. In fact, packaging can be the gating factor in achieving high performance while meeting the cost objectives in many microelectronics and computer systems. Essentially, an RF package must provide:

1. Connections to the mounted chips for power and signal lines.
2. A base to attach the active die and any associated components.
3. A means of removing unwanted heat.
4. A structure to protect and maintain the integrity of connections and chips while providing a platform for handling and external markings for identification.

One obvious way to reduce cost is



2. Over-molded plastic packages (left) can effectively and reliable encapsulate devices at power levels of 60 W and more (right).



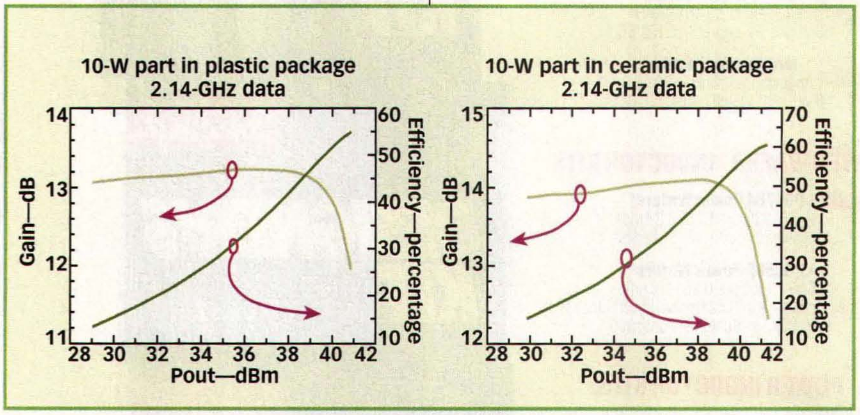
3. These cross-sectional views compare over-molded plastic- (left) and ceramic-packaged (right) power LDMOS devices.

by eliminating the costly ceramic ring, and its cumbersome and expensive brazing process. Fortunately, innovations in polymer materials (plastics) have made this practical (Fig. 2). There are two classes of synthetic polymers: thermoplastic and thermoset materials. Thermoplastics are processed by means of heat and pressure alone, without a chemical reaction. Upon cooling, thermoplastics either crystallize or transform to a glassy state. Thermosetting polymers (epoxies, bakelite, formica) chemically react upon the application of heat, causing an increase in the molecular weight. This chemical reaction leads to full conversion of all reactive groups to produce a polymer with substantial hardness, high heat distortion temperature, and both good chemical and physical resistance.

When encapsulating a semiconductor chip with a polymer, the chip is typically connected to the package lead frame via wire bonding; subsequently they are encapsulated in a polymeric insulator, which serves as a dielectric insulator and shields against environmental degradation. **Figure 3** offers a comparison of ceramic and over-molded plastic packages.

Over-molded packages do alter RF performance. In a ceramic package, chips and bond wires sit in an air cavity. In a plastic package, the polymer material surrounds and is in contact with the devices and bond wires. Since polymers have a higher dielectric constant than air, parasitics are marginally higher in a plastic package, resulting in slightly decreased output power and gain compared to the same device in a ceramic package. However, by using appropriate device design, layout, and wire-bonding techniques, the impact of plastic-package parasitics could be minimized to less than 0.5 dB **(Fig. 4)**.

In March 2003, Agere Systems (Allen-



4. Through careful, design, layout, and bond-wiring techniques, the electrical performance of a plastic package (left) can approach that of a more expensive ceramic package (right).

town, PA) unveiled a new line of 21 breakthrough transistors targeting the wireless base-station PA market. Based on traditional ceramic packaging, these products enabled much cooler, smaller, and less expensive wireless base stations. By achieving new thermal performance levels, these semiconductor products offered the potential to cut in half the number of cooling fans in base stations, offering service providers lower capital costs and operating expenses while also reducing noise pollution. The company is now migrating to next-generation RF devices assembled in high-volume over-molded plastic packages **(Fig. 5)**.

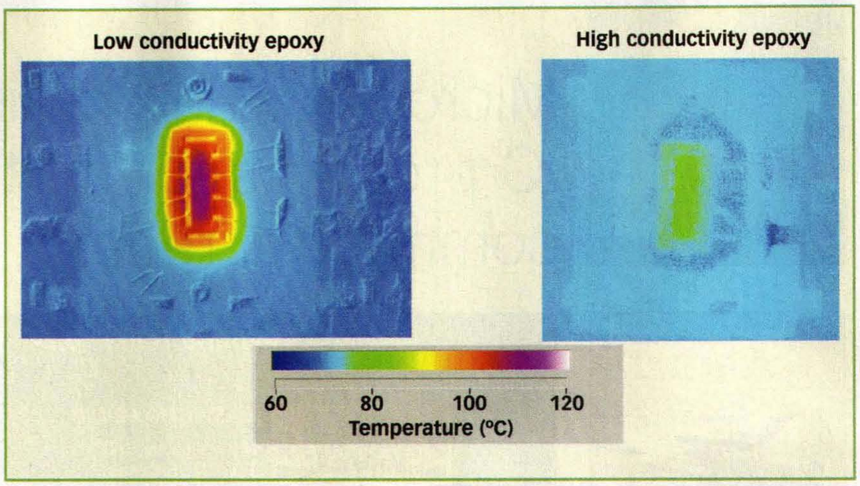
While early implementations of plastic packages solutions offered some cost reduction, the use of internal assembly lines hindered potential cost savings. A more attractive approach is the use of high-volume packaging facilities, where significant capital costs, knowledge, and innovations are shared among multiple product lines. This is directly analogous to the significant cost reduction experienced by IC design companies who chose to use world-class external foundries.

The latest family of RF power products from Agere is housed in over-molded plastic Power Small Outline Packages (PSOPs) from Amkor Technologies (West Chester, PA). Nearly one billion of these packages have been produced to date, with the high yields, low cost, and high reliability required by the RF electronics market.

Agere's PSOP-packaged transistors approach the performance of the same devices mounted in ceramic housings.

The small, thin housings were designed to operate reliably in the harshest environments. Particular attention was focused on material sets and assembly processes to address user issues such as flatness, coplanarity, wire sweep, delamination, solderability, and cost. Over-molded plastic technology as applied to RF power transistors offers another important technology and business advantage: this packaging places RF power transistors into the accepted mainstream manufacturing process required by the electronics and communication industries.

The company's PSOP-packaged transistors approach the performance of the same devices mounted in more-expensive ceramic housings, delivering excellent results through 2.1 GHz at significant cost savings. These reliable over-molded plastic packages also meet both current and 2006 environmental standards while being compatible with lead-free board assembly technologies. In addition, the company has shown that a new generation of highly conductive epoxies can be used to perform the die-attach operation, replacing the lead-based solders of earlier solutions. Agere subjects its over-molded ICs to an extensive set of tests to ensure that the low-cost over molded part is a suitable replacement for traditional ceramic parts. Early in the second quarter of



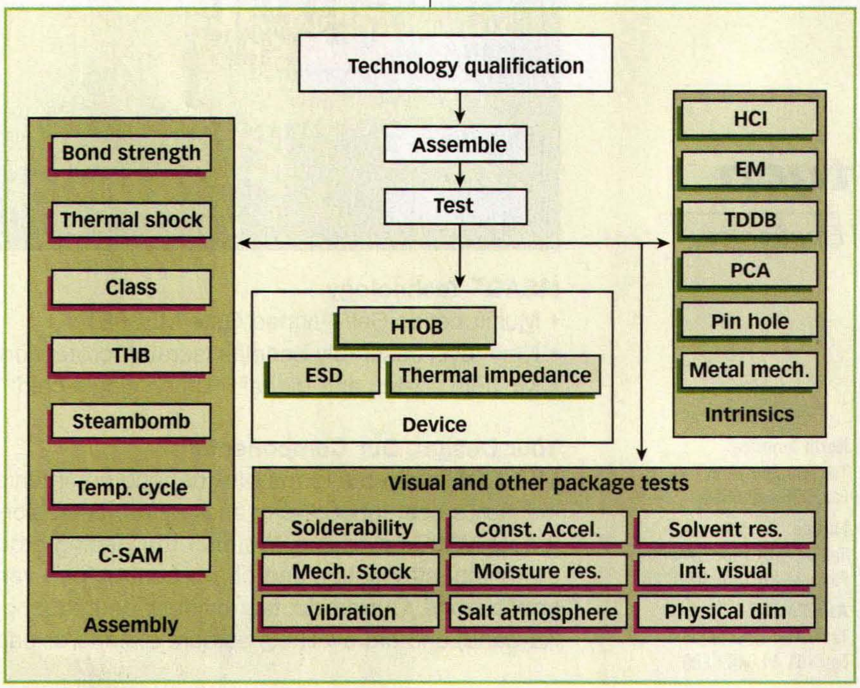
5. Using high-conductivity epoxy for die attachment (right), improved thermal performance can be achieved in a plastic package compared to a similar device attached with low-conductivity epoxy.

2004, the over-molded LDMOS parts will meet the thermal, electromagnetic, mechanical, and physical qualifications outlined in **Fig. 6**.

With time, over-molded plastic RF power transistors will lead to significant cost reductions for wireless base-station equipment designers and network operators. It is also feasible that the reduced power and space requirements will enable operators to deploy base stations in new and novel ways. The packaging technology innovation is certain to spur other packaging innovations. For example, Agere is already working on novel air-cavity solutions for higher-output-power devices. In addition, these packaging concepts can be extended to integrated modules for even greater cost reductions without compromising performance. MRF

ACKNOWLEDGMENTS

The authors would like to thank their colleagues at the Analog Products Division of Agere Systems for their work supporting this new package development.



6. Over-molded plastic-packaged LDMOS devices are being developed this year to meet these requirements.

(continued from p. 13)

evaluated for satellite use by the major satellite players. Hardware is in production for microwave links in the Philippines and Indonesia. Two factories are now licensed to produce hardware in China and Hong Kong.

The Baranski paper is typical of the flawed critics' work. Baranski assumed a filter bandwidth equal to the Nyquist bandwidth spread for VMSK/1 and came up with a 37-dB C/N to function. I wrote him to say that I am surprised it wasn't worse. Wrong filter. The method uses a special ultra-narrowband filter. It will not work otherwise. There is also a critique by Dr. Tomazic on the Internet. Again, wrong filter. His paper provided the artwork for some of the papers on the VMSK.org website. I thanked him for his contribution.

The method violates Carson's rule, and does not conform to the Nyquist bandwidth. It does not violate Shannon's Limit in any way. The correct analysis for Shannon shows a limit of 0 dB or better. See VMSK.org for details on filters and Shannon. The Shannon Channel capacity equation applied incorrectly proves absolutely that there isn't enough power available in the US to transmit a signal across the room.

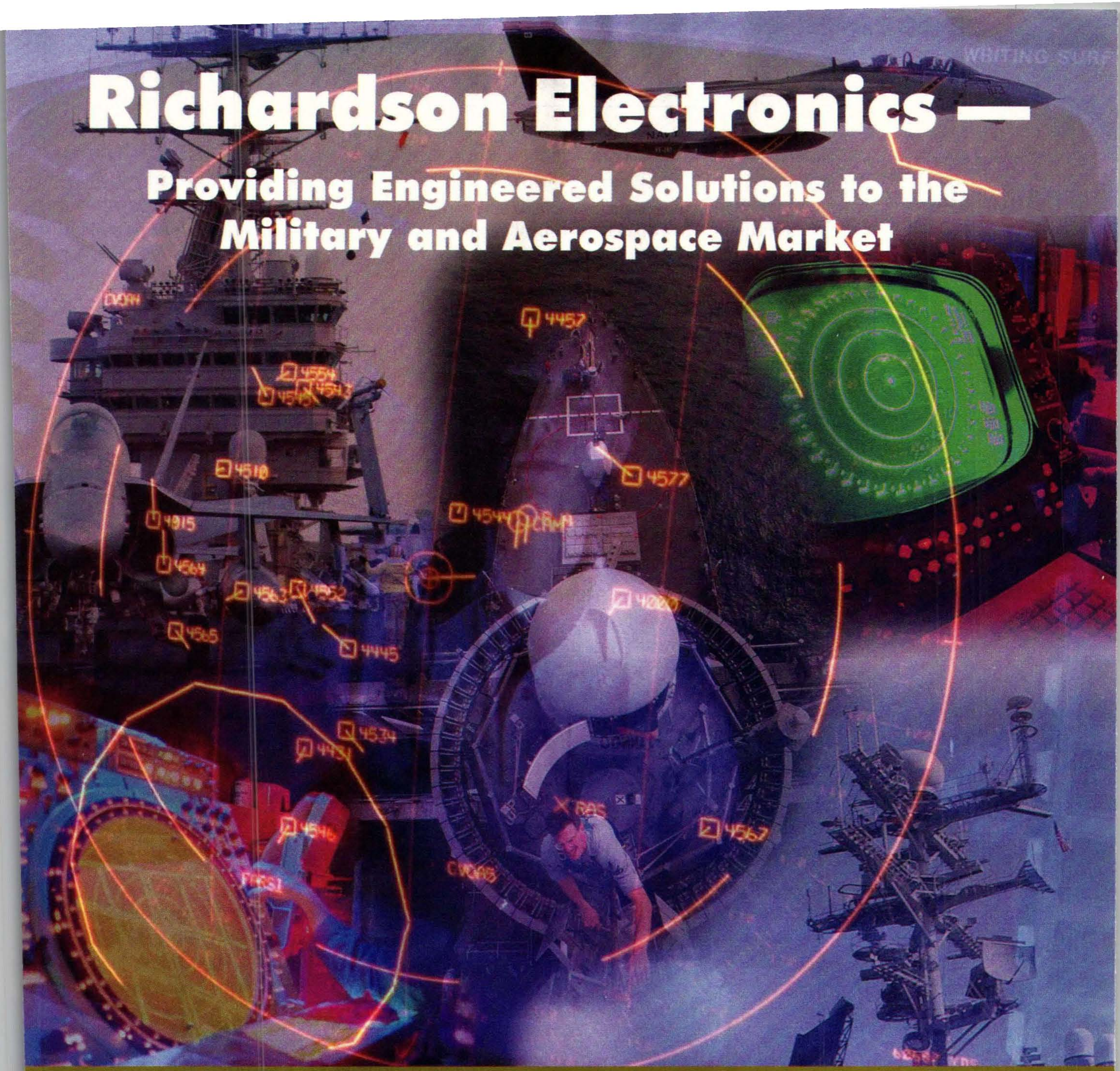
There is a slight goof in the article. The equations used beta in radians. The correct formula should have used sine squared.

Editor's Note: Microwaves & RF *is not responsible for the content of external websites.*

Article Correction

▶▶IN THE COVER STORY of the January 2004 issue, "Load-Pull Tuners Are Frequency Selective," by Christos Tsironis and Roman Meierer (p. 97), an incorrect phone number was listed for Focus Microwaves, Inc. The correct number is (514) 684-4554. We regret the error, and apologize for any confusion that it may have caused.

The Editors of Microwaves & RF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Considering Antennas For GPS Automotive Uses

ACTIVE ANTENNA TECHNOLOGY plays a major role in vehicular Global Positioning System (GPS) receivers. Active GPS antennas essentially consist of three components: a patch element, filter, and low-noise amplifier (LNA). For those working with GPS systems, application note GPS01 from M/A-COM, "GPS Antenna Considerations for Automotive Applications," provides a useful tour through the importance of three three components to a successful GPS antenna design.

The GPS antenna element is often fabricated by means of microstrip patch technology. For square ceramic resonator pucks that measure 1 in. on a side, and thicknesses ranging from 0.16 to 0.25 in., the dielectric constant of the ceramic material is about 20. A variety of techniques are available to achieve right-hand circular polarization (RHCP) from a patch element, including the use of a polarization slot, offset feed points, and polarization tabs.

To provide an antenna with good RHCP performance, the axial ratio is critical. The higher the axial ratio, the more elliptical the polarization will be and the lower the antenna gain with respect to RHCP. The application note includes a simple formula that correlates axial ratio to circular gain, with a gain correction factor for making the transition from measured linear gain and axial ratio to circular gain. The four-page application note also provides information on controlling resonant frequency, including the dielectric-loading effects of the antenna package radome, the relationship of resonant frequency performance to the size of the ground plane, how to optimize the bandwidth for a particular GPS antenna design, and how the measure antenna voltage-standing-wave ratio (VSWR).

The note also offers details on the other two key active GPS antenna elements, the LNA and the bandpass filter. The positioning of the three antenna components is critical to the overall noise figure of the assembly, and the printed-circuit-board (PCB) layout must also be properly executed to achieve optimum performance. Copies of the note can be downloaded for free from the company's website.

M/A-COM (a Tyco Company), 1011 Pawtucket Blvd., Lowell, MA 01853; (800) 366-2266, (978) 442-5000, FAX: (800) 618-8883, Internet: www.macom.com.

The application note addresses some of the concerns surrounding UWB technology and tackles some of the challenges in generating UWB signals and testing UWB systems.

Tackling Generation And Reception Of UWB Signals

ULTRAWIDEBAND (UWB) WIRELESS technology has stirred much debate among designers of more traditional wireless communications technologies. The technology, which involves the use of very low-power, time-sequenced pulses to carry broadband audio, video, and data, occupies wide spreads of existing bandwidth, albeit at power levels that resemble noise to existing signals. The concern among established system users, such as those working at GPS, cellular, and wireless-local-area-network (WLAN) frequencies, is whether the unlicensed use of UWB transmitters will cause interference to other wireless systems. A timely application note (AN-14a) from Picosecond Pulse Labs, "UWB Signal Sources, Antennas & Propagation," written by the company founder, James Andrews, addresses some of the concerns surrounding UWB technology and tackles some of the challenges in generating UWB signals and testing UWB systems.

The 11-page application note reviews the history of UWB technology and briefly summarizes the UWB spectrum issues. It discusses the difficulties of generating UWB signals in the FCC-approved 3.1-to-10.6-GHz band (noting that pulse durations (or risetimes) need to be on the order of 50 to 100 ps. The note points out that the Non-Linear Transmission Line (NLTL) Edge Compressor has the potential to generate the type of signals needed by UWB systems.

The note also highlights the type of antennas needed for successful UWB system operating and testing, noting that one of the few commercial firms now selling UWB antennas is Farr Research (www.farr-research.com). At present, the National Institute for Standards and Technology (NIST) recommends conical antennas for transmission and TEM horns for reception.

Copies of the note, which reviews several other antenna options for UWB testing, are available from free download from the company's website.

Picosecond Pulse Labs, P.O. Box 44, Boulder, CO 80306; (303) 443-1249, Internet: www.picosecond.com.

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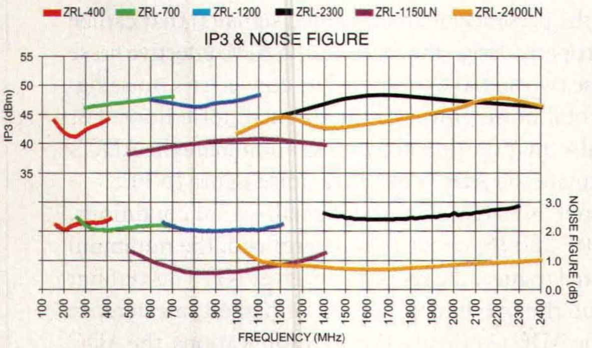

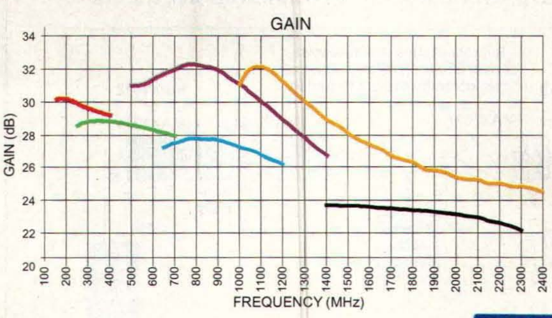

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See our 244 page RF/IF Designer's Guide in EEM (Electronic Engineers Master)

cover story

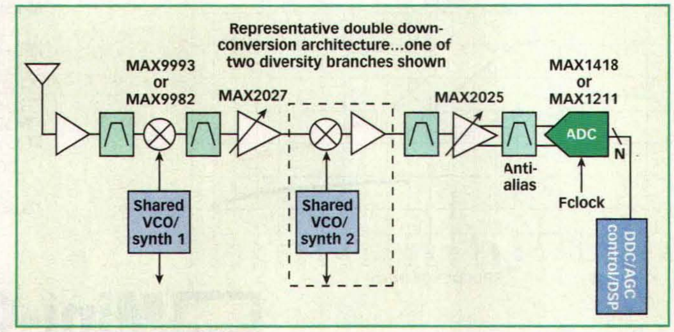
Agile ADCs Enable Digital Cellular Receivers

High-performance analog-to-digital converters and supporting RF components are needed for effective digital receiver designs in cellular base transceiver stations (BTSs).

Digital receivers for cellular communications systems require the highest performance levels from analog-to-digital converters (ADCs) and their supporting cast of RF components. The signal chain must be sensitive enough to capture low-level signals, while providing enough dynamic range to handle high-level interfering signals (blockers). Fortunately, the MAX1418 15-b, 65-MSamples/s ADC or MAX1211 12-b 65-MSamples/s ADC from Maxim Integrated Products (Sunnyvale, CA) in combination with the company's 2-GHz MAX9993 or 900-MHz MAX9982 integrated mixers provide exceptional dynamic range for two of the most critical stages in a receiver. In addition, the firm's MAX2027 and the MAX2055 intermediate-frequency (IF) digital variable-gain amplifiers (DVGAs) provide high third-order output intercept (OIP3) performance with the required gain adjustment range for many applications.

For the subsampling receiver architecture shown in **Fig. 1**, stringent noise and distortion requirements are placed on the ADC. In receiver applications, the lower level desired signal is digitized alone or in the presence of an unwanted signal(s) that can be significantly larger in amplitude. To properly design the receiver, the ADC effective noise figure must be determined under these two signal extremes. The converter's noise figure is determined by comparing its total noise power to the thermal noise floor. For small analog input signals, the thermal + quantization noise power dominate the ADC's noise floor, which is used to approximate the ADC's effective noise figure (NF).

In practice, once the ADC's effective NF is known under small-signal conditions, and the cascaded NF of the analog (RF and IF) circuitry is determined, the minimum power gain ahead of the ADC is selected to meet the required receiver NF. The amount of power gain places an upper limit on the maximum blocker, or highest interference level the receiver can tolerate before the ADC overloads. For BTS applications, the ADC often does not have sufficient dynamic range to meet both the NF requirements (receiver sensitivity) and maximum blocker requirements without implementing automatic gain control (AGC). The AGC can be included either in the RF stages, IF stages, or both.

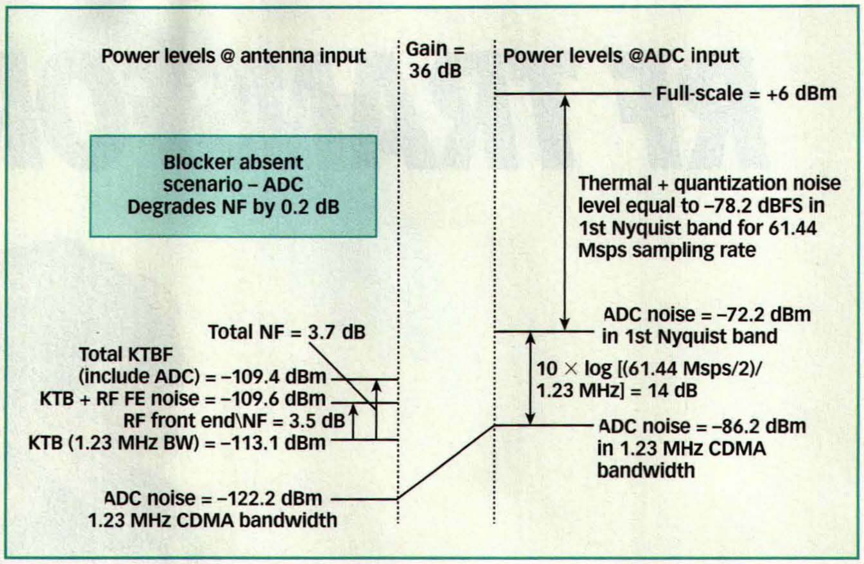


1. This block diagram shows a subsampling receiver architecture.

DAN TERLEP
Product Definer
Maxim Integrated Products, Inc., 120 San Gabriel Dr., Sunnyvale, CA 94086; (408) 737-7600, FAX: (408) 737-7194, Internet: www.maxim-ic.com.

Other converters in the MAX1418 family are optimized for baseband performance where the input frequency (f_{INPUT}) is less than one-half the clock frequency ($f_{CLOCK}/2$). Operating in this frequency range and using these baseband-optimized parts provide the best possible converter dynamic range. These converters include the MAX1419, which is optimized for a sampling rate of 65 MSamples/s, and the MAX1427, which is optimized for a sampling rate of 80 MSamples/s, both with spurious-free-dynamic-range (SFDR) performance equal to –94.5 dBc at baseband.

As an example, the MAX1418 was used as the converter in a front-end signal chain (using specifications listed in **Table 1**). The MAX1418 can be used with a 14-b interface by not connecting the least-significant bit (LSB). If so used, there is a slight signal-to-noise-ratio (SNR) performance penalty and the SFDR performance remains essentially unaffected. **Figure 2** shows the ADC noise contribution in the absence of a large-level blocker. Assume all the analog circuitry in front of the ADC has a cascaded noise figure of 3.5 dB. As a first approximation, suppose a designer's goal is for the ADC to degrade the overall receiver NF by no more than 0.2 dB to meet some target sensitivity in a code-division-multiple-access (CDMA) base-station receiver. This NF value should provide sufficient margin to the air-interface requirements, which is also dependent on the final detector's bit-energy-to-noise-power-spectral-density-ratio (E_b/N_o) requirement. If the MAX1418 thermal + quantization noise floor value from Table 1 is used, an equivalent NF of 26.9 dB can be calculated when the device is clocked at 61.44 MSamples/s (a 50× chip rate). The ADC noise in the 1.23-MHz CDMA channel bandwidth is 14 dB lower than the noise in the Nyquist bandwidth due to the processing gain achieved. An overall gain of 36 dB is needed to achieve the desired cascaded receiver noise figure value of 3.7 dB.



2. This scenario represents the ADC noise contribution for no blocker.

With 36-dB gain ahead of the ADC, a maximum single tone blocker level above –30dBm at the antenna terminal will exceed the ADC full-scale input. The cdma2000 cellular base-station standard specifies a maximum allowable blocker level of –30 dBm at the antenna terminal. For this example, a 6-dB gain reduction was used to increase the largest allowable blocker signal applied to the ADC providing margin to the standard's specification. Assuming allowable headroom of 2 dB, a 6-dB gain reduction results in a maximum blocker level of –26 dBm at the antenna and +4 dBm at the ADC input **(Fig. 3)**. The cellular standards allow 3-dB degradation in overall (noise + distortion) relative to reference sensitivity when a single-tone blocker is present. The allocation of individual noise and distortion components is left to the designer.

Suppose the designer allows the RF front-end cascaded noise plus distortion to degrade the NF by 1 dB (from the nominal 3.5 dB) when the blocker is present with 6 dB of AGC applied. With only 30 dB of gain in front of the ADC and an effective NF of 29.4 dB determined by the ADC SNR performance, the cascaded receiver NF is 5.7 dB in the "blocked condition," which is a 2-dB degradation from the 3.7-dB NF calculated for receiver sensitivity. Because this calculation does not take into account the spurious performance, an additional 1-dB degradation can be allowed for the ADC's SFDR performance. Instead of calculating noise and SFDR contributions separately, the signal-to-noise-and distortion (SINAD) figure of merit could have been used to compute the effective NF when a blocker signal is present.

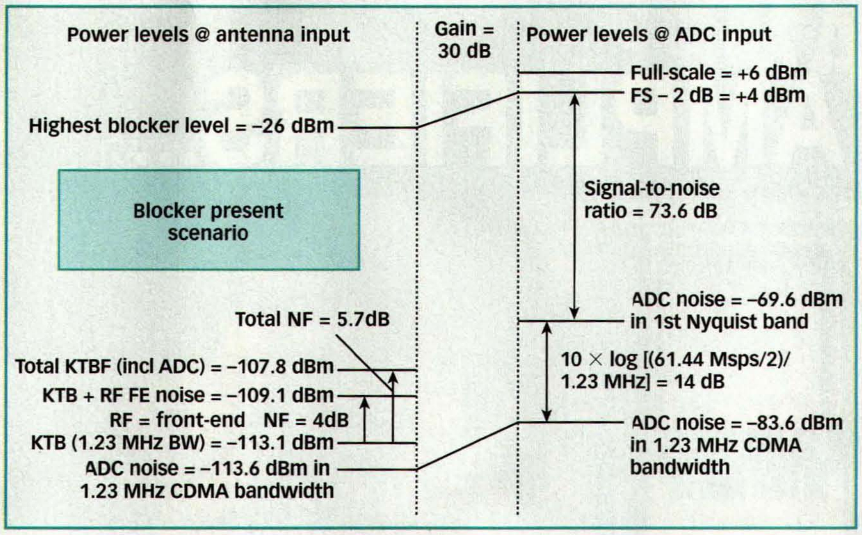
The subsampling architecture can be used with a single downconversion architecture if sufficient SNR and SFDR

Table 1: The MAX1418 ADC at a glance

PARAMETER	CONDITION	SYMBOL	TYP. VALUE	UNITS
Resolution		N	15	Bits
Analog input range		VID	2.56	Vp-p
Differential input resistance		RIN	1	kΩ
AC SPECIFICATIONS	**f_{CLK} = 65 Msps**			
Thermal + quantization noise floor	Analog input < –35dBFS	Nfloor	–78.2	dBFS
Signal-to-noise ratio Analog in = –2 dBFS	f_{IN} = 70 MHz	SNR	73.6	dB
Spurious-free dynamic range Analog in = –2 dBFS	f_{IN} = 70 MHz	SFDR	84	dB
Signal-to-noise-and-distortion Analog in = –2 dBFS	f_{IN} = 70 MHz	SINAD	73.3	dB

performance can be obtained from the converter at higher IFs. Maxim's MAX1211 is a 12-b 65 MSamples/s converter **(Table 2)** also shows the performance of an improved version, available in about one month) designed with this architecture in mind along with pin-compatible 80- and 95-MSamples/s versions that will soon be released. The family of converters allows direct-IF sampling for input signals to 400 MHz along with advanced features such as differential or single-ended clock input, clock duty cycles from 20 to 80 percent, data valid indicator allowing the simplification of clock and data timing, 2's complement or gray code digital output data format, and a compact 40-pin thin QFN package (6 × 6 × 0.8 mm).

Single-conversion architectures offer significant advantages compared to double-downconversion (DDC) receivers. For example, by eliminating the second downconversion mixer, second-IF gain stages, and second LO synthesizer circuitry, the parts count and board space can be reduced by approximately 10 percent and cost by \$10 to \$20. Frequency planning is also simpler. A cdma2000 personal-communications-services (PCS) receiver, for example, might have a first IF centered in the sixth Nyquist band at 169 MHz and bandwidth of approximately 1.24 MHz for a sample rate of 61.44 MSamples/s and synthesizer reference frequency of 30.72 MHz. With the same first IF, a DDC architecture assumes a second IF



3. This scenario shows the ADC noise contribution with a blocker signal present.

centered in the second Nyquist band at 46.08 MHz.

Spurious search assumptions for both architectures (for an RF carrier near the upper end of the PCS band) are listed in **Table 3.** The simpler architecture yielded 134 total spurious signals in the RF receive band, receive image band, IF band, and IF image band, mostly higher-order products that will not degrade receiver performance. The DDC approach yielded over 2400 spurious products, in the RF and both IF bands. Although many of these products can be reduced by careful PCB layout and filtering, a significant number of lower-order spurious signals will be difficult to minimize.

Before an ADC can convert received signals to the digital realm, those signals must be translated down in frequency through a mixer. By their nonlinear nature, mixers produce undesired spurious signal products according to the well-known relationship

$$f_{IF} = \pm m f_{RF} \pm n f_{LO}$$

where:

f_{IF}, f_{RF}, and f_{LO} refer to the frequencies of the signals at the mixer's IF, RF, and LO ports, respectively, and m and n are integer harmonics of both the RF and LO frequencies that mix to create numerous combinations of spurious products.

Traditional passive mixers employ diodes to achieve the signal mixing effects. More recently, however, integrated active mixers, such as the balanced models MAX9993 and MAX9982, are becoming more popular. Balanced mixers reject certain spurious responses when m or n is even resulting in excellent second-order harmonic performance. Ideal double-balanced mixers reject all responses where m or n (or both) is even. In all double-balanced mixers, the IF, RF, and LO ports are mutually isolated. With properly designed baluns, such mixers can have overlapping RF, IF, and LO bands. LO noise in a mixer reciprocally mixes with high-level input blocking signals to desensitize a receiver.

In addition to providing gain (rather than the loss of a passive mixer), the MAX9993 and MAX9982 mixers have integrated RF baluns on the RF and LO ports and built-in low-noise LO buffers that result in minimal receiver desensitization when blockers are pre-

Table 2: The MAX1211 AC performance at a glance

PARAMETER	CONDITION	SYMBOL	TYP. VALUE	UNITS
Resolution		N	12	Bits
Analog input range		VID	2	Vp-p
Differential input resistance		RIN	15	kΩ
AC SPECIFICATIONS	F_{CLK} = 65 Msps			
Thermal + quantization noise floor	Analog input < –35 dBFS	Nfloor	69.3	dBFS
Signal-to-noise ratio	f_{IN} = 32.5 MHz	SNR	68.9	dB
Analog in = –0.2 dBFS	f_{IN} = 175 MHz		67.4	
Spurious-free dynamic range	f_{IN} = 32.5 MHz	SFDR	89.7	dB
Analog in = –0.2 dBFS	f_{IN} = 175 MHz		76	
Signal-to-noise-and-distortion	f_{IN} = 32.5 MHz	SINAD	68.8	dB
Analog in = –0.2 dBFS	f_{IN} = 175 MHz		66.8	

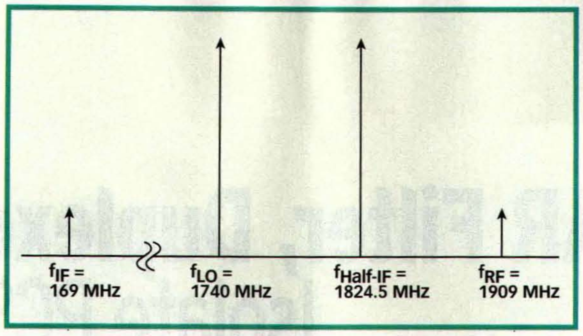
sent. For example, if an LO driving the MAX9993 has a sideband noise performance of –145 dBc/Hz, the typical LO noise for the mixer is –164 dBc/Hz. As a result, the composite sideband noise performance is degraded by only 0.05 dBc/Hz to –144.95 dBc/Hz.

A particularly troublesome second-order mixer spurious response is the half-IF response which occurs when m = 2 and n = –2 for low-side rejection and when m = –2 and n = 2 for high-side rejection. Following the 169-MHz IF example, if the desired RF signal is 1909 MHz **(Fig. 4)**, the corresponding LO signal is 1740 MHz. Though the CDMA RF and IF carrier occupies a 1.24-MHz bandwidth, it's illustrated as a single frequency indicating the center carrier frequency. An undesired RF signal at 1824.5 MHz will cause a half-IF spurious product at 169 MHz:

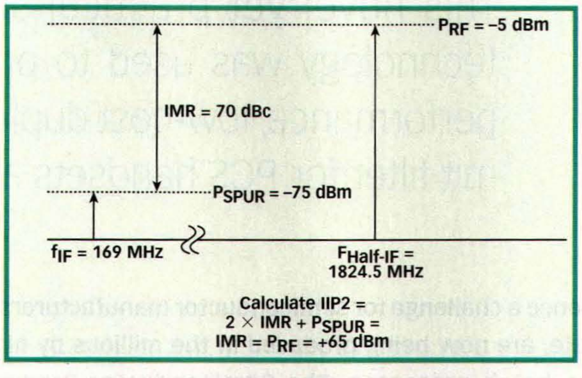
$$2f_{Half\text{-}IF} - 2f_{LO}$$
$$= 2(f_{RF} - f_{IF}/2) - 2(f_{RF} - f_{IF})$$
$$= 2f_{RF} - 2f_{IF}/2 - 2f_{RF} + 2f_{IF} = f_{IF}$$

which results in 2(1824.5 MHz) – 2(1740 MHz) = 169 MHz. The amount of rejection, called the 2 × 2 spurious response, can be predicted from the mixer's second-order intercept point (IP2). The 2 × 2 IMR or spurious values in **Fig. 5** are taken from the data sheet for the MAX9993 mixer. The signal levels are referred to the input of the mixer for which the input IP2 (IIP2) performance is calculated:

$$IIP2 = 2IMR + P_{SPUR} = IMR + P_{RF} = 2(+70\ dBc) + (-75\ dBm) = +70\ dBc + (-5\ dBm) = +65\ dBm$$



4. These are the frequency locations for desired f_{RF}, f_{LO}, f_{IF}, and undesired $f_{Half\text{-}IF}$ products.



5. This plot shows the second-order intercept calculation for signals referred to the mixer input (IIP2).

Image-reject filters used in the RF path immediately ahead of the mixer attenuate any amplifier harmonics. The noise filter in the LO path attenuates harmonics caused by the LO injection source. High-level input signals create distortion or intermodulation products and can be quantified by calculating the intercept point, either at the input or output of the device or system (the output intercept point is merely the input intercept point plus the gain (in dB) of the device or circuit under test). For the case where the mixer LO power is held constant, the order of the intercept point or distortion product is determined only by the RF multiplier and not by the LO multiplier since only variations in the RF signal are of concern. The order refers to how fast the amplitudes of the distortion products increase with a rise in input level.

The high-speed ADCs are well suited for designing digital cellular receivers with low noise and wide dynamic range and, with the firm's active mixers, form a simple high-performance single-conversion receiver. The addition of the company's DVGAs provide typical OIP3 performance of +40 dBm over a wide gain-adjustment range, to complement the ADC performance. For more information on any of these components, visit the company's website. **Maxim Integrated Products, Inc., 120 San Gabriel Dr., Sunnyvale, CA 94086; (408) 737-7600, FAX: (408) 737-7194, Internet: www.maxim-ic.com.**

Table 3: Assumptions for spur-search comparison of SDC and DDC architectures

SDC	DDC	PARAMETER	VALUE
X	X	Receive band:	1904.3800 to 1905.6200 MHz
X	X	Clock frequency:	61.4400 MHz
X	X	Max clock harmonic:	30
X	X	Synthesizer ref freq:	30.7200 MHz
X	X	Max synthesizer harmonic:	40
X	X	First injection LS:	1736.0000 MHz
X	X	Max 1st LO harmonic:	5
X	X	Receive image band:	1566.3800 to 1567.6200 MHz
X	X	First IF band:	168.3800 to 169.6200 MHz
	X	Second injection LS:	122.9200 MHz
	X	Max 2nd LO harmonic:	5
	X	1st IF image band:	76.2200 to 77.4600 MHz
	X	Second IF band:	45.4600 to 46.7000 MHz

REFERENCES

1. Relevant application notes can be found on the website at www.maxim-ic.com, including AN 728, "Defining and Testing Dynamic Parameters in High-Speed ADCs, Part 1," AN 729 "Dynamic Testing of High-Speed ADCs, Part 2," AN 1197 "How Quantization and Thermal Noise Determine an ADC's Effective Noise Figure," AN 1929 "Understanding ADC Noise for Small and Large Signal Inputs for Receiver Applications," AN 1838 "Mixer 2x2 Spurious Response and IP2 Relationship," AN 2021 "Specifications and Measurement of Local Oscillator Noise in Integrated Circuit Base Station Mixers," and AN 2371 "Consider Overall Cascaded Performance When Comparing Integrated RF Frequency Mixers to Passive Mixer Solutions."

2. James Tsui, *Digital Techniques for Wideband Receivers*, Artech House, Norwood, MA, 1995.

3. Peter Vizmuller, *RF Design Guide, Systems, Circuits, and Equations*, Artech House, Norwood, MA, 1995.

4. Jhong Sam Lee and Leonard E. Miller, *CDMA Systems Engineering Handbook*, Artech House, Norwood, MA, 1998.

FBAR Filter, Duplexer Isolate PCS Signals

This novel yet practical semiconductor technology was used to produce a high-performance, low-cost duplexer and transmit filter for PCS handsets and data cards.

JACK BROWNE
Publisher/Editor

Filters, once a challenge for semiconductor manufacturers to fabricate, are now being produced in the millions by high-volume batch processes. The Semiconductor Products Group of Agilent Technologies (Palo Alto, CA), for example, has already shipped more than 20 million of its thin-film bulk-acoustic-resonator (FBAR) duplexers. The components, which now ship at a rate of 2 million per month, are designed into nine of the top ten CDMA phone manufacturers' US PCS band handsets. Adding strength to its position, the company announced the availability of a new FBAR PCS duplexer, the model ACMD-7401, and a new FBAR PCS-band transmit filter, the model ACPF-7002.

The FBAR technology is a silicon-based semiconductor process that can be readily integrated into front-end modules and other silicon-based semiconductor solutions. FBAR components are environmentally sealed by the firm's innovative Microcap packaging, which involves bonding a cap wafer onto the FBAR wafer.

The ACMD-7401 duplexer, for example, measures just 5 × 5 mm with a maximum height of 1.4 mm—about one-tenth the size of competing solutions. Designed for PCS handsets and data cards, it has a receive band of 1930 to 1990 MHz and transmit band of 1850 to 1910 MHz. Although 66-percent smaller than the company's first-generation FBAR duplexer (model HPMD-7904), the duplexer exhibits 2.2 dB typical receive-band insertion loss and 1.8 dB typical transmit band insertion loss. The duplexer achieves 44 dB receiver noise blocking and 54 dB typical transmit interferer blocking at power levels to +30 dBm. Its low temperature coefficient of 25 PPM/°C ensures stable performance with temperature.

The ACPF-7002 PCS transmit filter measures just 1.6 × 2.0 mm, but rivals the performance of much larger split-band SAW transmit filters with switches. The FBAR transmit filter features 2.5 dB typical insertion loss over the PCS transmit band of 1850 to 1910 MHz with typically 37 dB rejection (minimum of 33 dB) from 1930 to 1990 MHz. The tiny filter, with minimum ripple of 2.5 dB and typical return loss of 11 dB from 1850 to 1910 MHz, handles power levels to +20 dBm. P&A: \$2.45 (ACMD-7401, 100,000 qty) and \$0.54 (ACPF-7002, 100,000 qty.); stock. **Agilent Technologies, Semiconductor Products Group, 5301 Stevens Creek Blvd., Santa Clara, CA 95051; (800) 235-0312, e-mail: semiconductorsupport@agilent.com, Internet: www.semiconductor.agilent.com.**

Darlington Gain Blocks Hurdle Reliability Problems

Based on a Darlington-pair architecture, these new gain blocks overcome the reliability issues of previous designs with usable performance from near DC to 6 GHz.

Gain blocks are used by the millions in commercial and military applications ranging from cable-television (CATV) systems to test instruments. Typically, these broadband amplifiers are designed with a pair of transistors in a Darlington configuration which, although providing high broadband gain, can suffer from reliability problems. But by using a mature in-house InGaP semiconductor process, and designing in safeguards, the engineering team at Celeritek (Santa Clara, CA) has developed a new line of Darlington-based gain blocks in the CGB7000 series that promises high reliability and excellent immunity to electrostatic discharge (ESD) over a frequency range of 01 to 6.0 GHz.

DR. DEAN BARKER
Director of Process Development
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Fifty years after US Patent No. 2663806 was issued to Sidney Darlington (December 22, 1953) for a variety of transistor and resistor combinations, the circuit configuration is still widely used in millions of Darlington-pair gain blocks. Unfortunately, such devices have several disadvantages, including poor ESD resistance, poor thermal resistance, and a difficult-to-test architecture. In one of the best-known Darlington configurations, resistors are connected in parallel with the base-collector and base-emitter junctions of the transistors. While an essential part of the biasing scheme, the resistors prevent thorough testing of the transistors, allowing some defects to go undetected until they become the cause of in-field failures. Although Darlington-pair gain blocks have suffered from reliability issues, they are still widely used today in test equipment, cellular base stations, and military systems.

The CGB7000 series of gain blocks was developed to transcend the shortcomings of traditional Darlington-pair gain blocks. Based on reliable InGaP heterojunction-bipolar-transistor (HBT) technology, the 11 devices exhibit thermal resistances ranging from 75°C/W in the high-output model CGB70012-

The CGB7000 series gain blocks at a glance

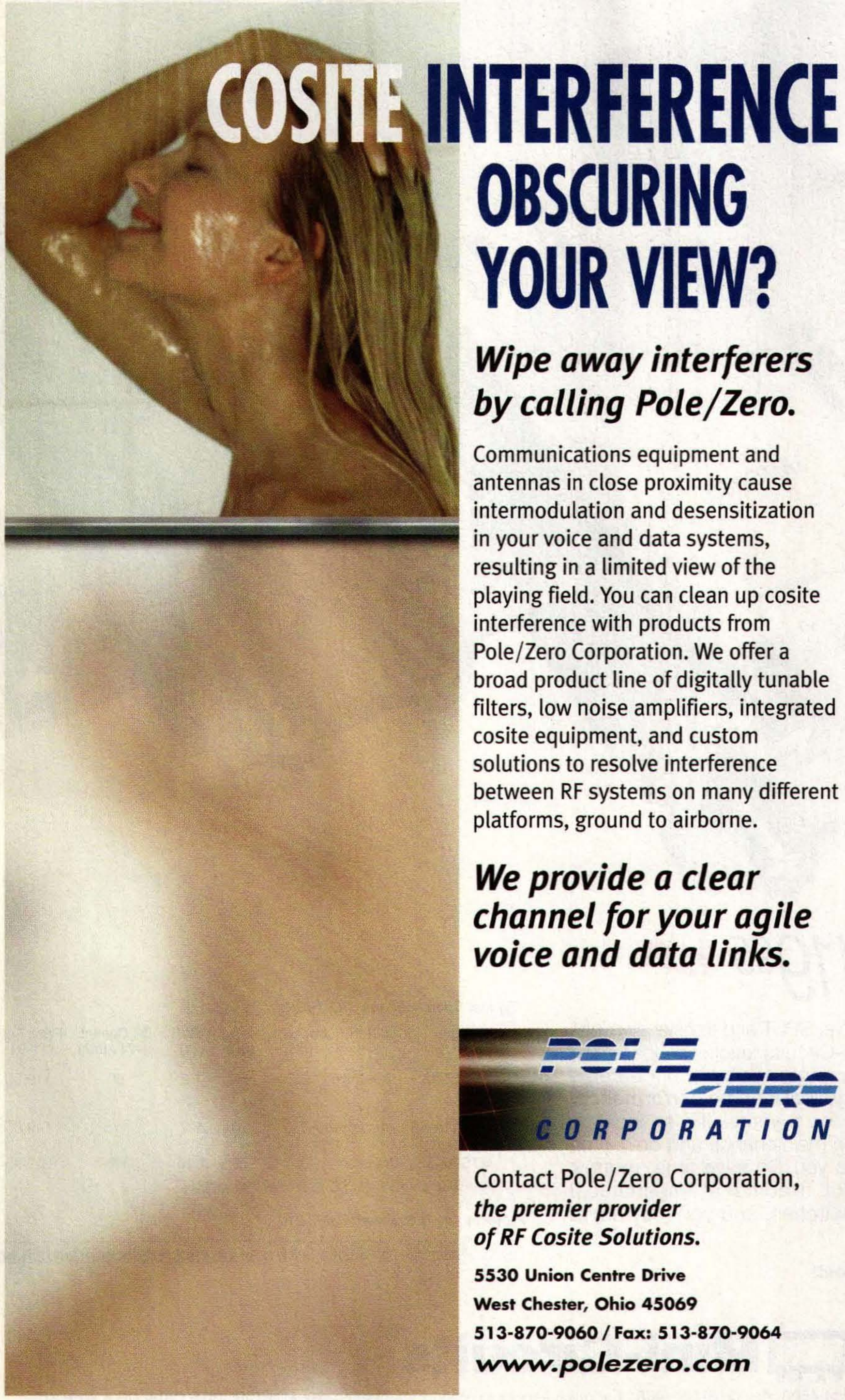
MODEL	FREQUENCY RANGE (GHz)	OUTPUT POWER (dBm)	GAIN (dB)	NOISE FIGURE (dB)	OIP3 (dBm)
CGB7001-SC	0.1 to 6.0	+14.2	20.8	3.3	+28.0
CGB7003-SC	0.1 to 6.0	+16.6	21.0	2.9	+31.5
CGB7004-SC	0.1 to 6.0	+17.0	16.5	3.6	+32.0
CGB7005-SC	0.1 to 6.0	+17.6	21.0	3.0	+32.5
CGB7006-SC	0.1 to 6.0	+18.0	15.5	5.0	+32.0
CGB7007-SC	0.1 to 6.0	+18.8	19.0	4.5	+34.0
CGB7008-SC	0.1 to 6.0	+18.8	21.5	3.2	+33.0
CGB7009-SC	0.1 to 6.0	+19.2	17.0	3.9	+34.8
CGB70010-SC	0.1 to 6.0	+20.3	21.5	3.2	+35.5
CGB70011-SC	0.1 to 6.0	+21.0	21.7	3.4	+36.0
CGB70012-SC	0.1 to 6.0	+20.3	16.0	4.3	+36.0

Note: Performance levels are at 850 MHz and test voltages of +5 VDC for models CGB7001 to 7005 and +8 VDC for models CGB7006 to 7012.

SC to 110°C/W in the high-gain/low-noise-figure model CGB7001-SC. Based on maximum device ratings, the projected mean time to failure (MTTF) for the two devices are 2500 years for the CGB7012-SC and 28000 years for the CGB7001-SC (with all other models in between).

To further enhance reliability, the gain blocks include protection circuits for immunity to ESD pulses as high as 1000 V based on the human-body model (HBM) and pulses as high as 2000 V using the charged-device model (CDM). Also, extra pads are included on each die to facilitate testing. This feature, which is not available on other Darlington-pair gain blocks, allows greatly enhanced testing of each die, permitting Celeritek's automated testers to detect and reject parts with subtle defects that might lead to field failures. Some of the tests enabled by the inclusion of extra pads include current-leakage tests (with failure limits set in the low microampere range); breakdown voltage tests (since low breakdown voltages are an indication of possible transistor reliability issues); DC current gain (beta) tests at low current for each of the transistors in the Darlington pair; measurements of base-collector and base-emitter diode forward-voltage drops at low current levels (deviations from typical results indicate latent defects); and measurements of the functionality of the ESD protection circuitry.

The CGB7000 series **(see table)** offers a variety of choices depending upon a specifier's needs for output power, gain, noise figure, and linearity [in terms of output third-order intercept OIP3) performance]. Not surprisingly, the lowest-power device, model CGB7001-SC, is the most reliable in terms of projected MTTF. The gain block provides 20.8 dB gain at 850 MHz with +14.2 dBm output power at 1-dB compression as well as a noise figure of 3.3 dB and OIP3 of +28 dBm. The CGB70011-SC delivers the highest output power, at +21 dBm, and also the highest gain, at 22 dB, with outstanding OIP3 of +36 dBm and still respectable noise figure of 3.4 dB. The gain blocks are useful in a variety of broadband and narrowband applications, as driver amplifiers for larger amplifiers, buffer amplifiers for mixers and local oscillators, and as intermediate-frequency (IF) amplifiers. The devices, which are supplied in SOT-89 packages, and in bare die form, with SOT-86 and ceramic micro-X packages available soon, can be used with a single bypass capacitor, optional RF choke, and two DC blocking capacitors. **Celeritek, Inc., 3236 Scott Blvd., Santa Clara, CA 95054; (408) 986-5060, FAX: (408) 986-5095, Internet: www. celeritek.com.**



Analyzers Test New 3G Wireless Formats

This series of spectrum analyzers can now fully characterize components and systems for TD-SCDMA and 1xEV-DV applications.

JACK BROWNE
Publisher/Editor

Third-generation (3G) cellular technologies are slowly but surely gaining ground on the promise of delivering the high data rates required for Internet access and multimedia at acceptable speeds. To ensure that designers of these systems have the right measurement tools, Agilent Technologies (Santa Rosa, CA) has added enhancements to their Performance Spectrum Analyzer (PSA) Series spectrum analyzers that allow them to characterize two of the most promising entrants: time-division synchronous code-division multiple access (TD-SCDMA) and 1x evolution, data and voice (1xEV-DV) technology. The analyzers have also been upgraded to work with external harmonic mixers at measurement frequencies as high as 325 GHz.

The PSA instruments include models with standard frequency ranges as wide as 3 Hz to 50 GHz. These are the company's highest-performance spectrum analyzers, with digital resolution-bandwidth filters as narrow as 1 Hz and as wide as 8 MHz. They feature outstanding stability, accuracy, and low noise (noise sidebands of –151 dBc/Hz at 6 MHz from the carrier).

1. Agilent's external mixers extend measurement range as high as 110 GHz, and to 325 with third-party mixers.

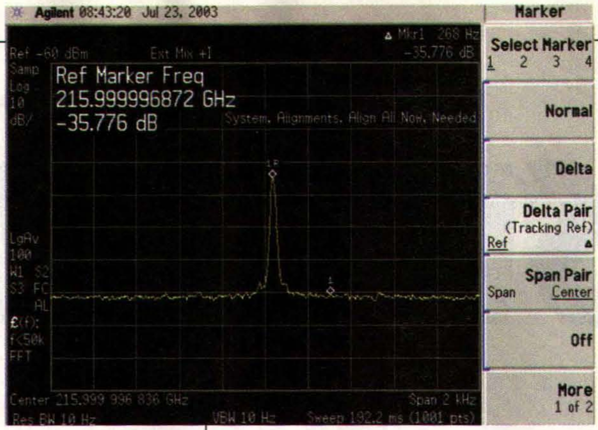
TD-SCDMA is virtually assured of being one of the primary access methods employed in the 3G wireless systems in China. Developed by the Chinese Wireless Telecommunications Standards group, TD-SCDMA is a unique access method that can increase the capacity of the network by using a single frequency band for both uplink and downlink transmission paths. It also dynamically allocates base-station resources for either uplink or downlink as dictated by traffic conditions. It was conceived to fully exploit the benefits of smart-antenna technology, and can simultaneously detect multiple parallel signals. The result is higher network capacity and greater overall throughput.

In order to give the PSA Series instruments the ability to characterize the transmit performance of TD-SCDMA components and systems, Agilent has created a TD-SCDMA measurement personality, available as Option 211. The enhancement provides the user with a dedicated interface that simplifies the measurement process, and allows the instruments to make power measurements on both uplink and downlink signals, including power versus time, transmit power, adjacent-channel power, multichannel power on up to 12 channels, spurious emissions, and spectrum emissions masks.

Within each of these categories, the user has various options for configuring the test routine. For example, when measuring transmit power, the display can include minimum, maximum, and mean values of a single burst or complete 10-ms frame, and root-mean-square (RMS) or log averaging are available. Spectrum emission masks that confine spurious emissions tests to within user-specified frequency bands display both spectrum and tabular results simultaneously. Other variables include average or peak detection, offset frequency, reference bandwidth, and limit values.

To complement the power-measurement-analysis capabilities of Option 211, Agilent has added TD-SCDMA modulation-analysis capability to its 89601A vector-signal-analysis software. This comprehensive analysis tool, which also supports a wide array of other access methods, allows designers to troubleshoot any modulation problems with a high level of detail.

1xEV-DV is the latest revision to the cdma2000 3G access method, following in the footsteps of 1xEV-DO (1x evolution, data only), and promises to increase network capacity and maximum attainable data rates by allowing more complex modulation schemes to be allocated on demand. Unlike



2. This 216-GHz signal was captured on a PSA with Option AYZ and a third-party mixer.

1xEV-DO, 1xEV-DV supports both voice and data traffic.

To allow the PSA Series analyzers to measure the performance of components in 1xEV-DV systems, Agilent has created new composite rho and code-domain tests that support the code-domain 8PSK and 16QAM modulation techniques used by the access method. The 1xEV-DV measurement personality is available as Option 214 over Option B78 cdma2000 measurement personality for the PSA Series and for Agilent's E4406A vector signal analyzer as well.

The number of applications for extremely high-frequency (EHF) systems has been limited mostly to military and scientific applications. However, there is an increasing need to make measurements at these frequencies to support these military and scientific systems as well as some commercial applications such as adaptive cruise control, and the fourth-generation (4G) wireless access methods currently in development. The PSA Series instruments' maximum measurement frequency of 50 GHz has been greatly expand with Agilent's introduction of Option AYZ, which features software that allows the instruments to employ external mixers from Agilent (to 110 GHz) and third parties (to 325 GHz).

Agilent's two mixer families include the 110 GHz 11970 Series harmonic mixers and the 75 GHz 11974 Series preselected mixers **(Fig. 1)**. To support the 11970 Series harmonic mixers or unpreselected third-party mixers, the analyzers can perform signal identification either with the image-shift or image-suppression techniques. The image-shift method moves the signals by a factor of the intermediate frequency (IF) divided by a user-specified harmonic number, and only the desired signal is shifted by the correct amount. The image-suppression technique automatically suppresses all images that are not the desired signal, leaving it as the only signal on the screen. The 11974 Series preselected mixers eliminate this signal-identification process, which significantly reduces measurement time.

Most third-party mixers require the bias voltage sent to the IF port of the analyzer to be adjusted for optimum performance. Option AYZ allows bias adjustment either locally or via IEEE-488 bus or LAN **(Fig. 2)**. Harmonic number can be set automatically by the analyzer or manually by the user to match the requirements of the mixer being used, and amplitude correction provides compensation for conversion loss. Option AYZ is available for the E4440A, E4446A, and E4448A PSA Series high-performance spectrum analyzers, and upgrade kits are also available for PSA Series analyzers already in service. **Agilent Technologies, Test and Measurement Organization, 5301 Stevens Creek Blvd., MS 54LAK, Santa Clara, Calif. 95052; Internet: www.agilent.com/find/PSA.**

Real-Time Analyzers Capture Complex Signals

Using frequency-domain triggering, these new real-time spectrum analyzers facilitate the capture of time-varying, periodic, or transient RF signals from DC to 8 GHz.

JACK BROWNE
Publisher/Editor

Capturing time-varying signals is a challenge for most measurement tools. Oscilloscopes, of course, are known for their ability to trigger on a high-speed event and show time-domain information about the captured waveform. But engineers seeking transient signal analysis in the frequency domain have had few options until now. With the introduction of the RSA2200A and RSA3300A Series of real-time spectrum analyzers from Tektronix, Inc. (Beaverton, OR), RF designers can now capture time-varying and transient signals at frequencies to 8 GHz, even when such signals carry wideband modulation.

The RSA Series real-time spectrum analyzers **(see figure)** allow an engineer to capture an entire frequency span at one time by triggering a selected bandwidth around a center frequency. In contrast, a conventional spectrum analyzer uses superheterodyne receiver techniques to sweep a local oscillator (LO) across a frequency span of interest, with a resolution-bandwidth filter also employed to suppress unwanted spurious and harmonic signals in the band of interest. The conventional method provides an excellent way to study stationary signals or signals with known narrow modulation bandwidths, although it is less than ideal for examining transient signals or signals with wide modulation bandwidths. The real-time spectrum analyzer captures a full time record of signals across an entire frequency span of interest. Similar to a still-photography camera, the real-time analyzer captures every signal occurring in the bandwidth of interest during the instant in which that "frame" was captured. The real-time spectrum analyzer can continue to capture and store these frames until stopped, storing a series of time-sequenced frequency spans that can reveal even the most difficult-to-capture transient signals.

The RSA2200A and RSA3300A Series real-time spectrum analyzers are ideal for capturing time-varying, periodic, or transient RF signals from DC to 8 GHz.

In addition to this wideband signal capture capability; the real-time spectrum analyzers share some of the triggering capabilities of modern digital storage oscilloscopes (DSOs). The analyzer can be programmed to trigger on specific frequency and amplitude conditions, for example, triggering on signals that fall within or outside of a defined amplitude/frequency mask.

The RSA2200A Series analyzers include RSA2203A, which operates from 10 MHz to 3 GHz (with optional extension to DC) and the RS2008A, which operates from 10 MHz to 8 GHz

(with optional extension to DC). Both instruments feature 2-MB signal capture memory and maximum signal capture bandwidth of 10 MHz.

The RSA3300A Series analyzers include the RSA3303A, which operates from DC to 3 GHz, and the model RSA3308A, which operates from DC to 8 GHz. Both instruments feature 15-MHz signal-capture bandwidths, and 64-MB standard signal-capture memory (with option for 256-MB signal-capture memory). Both series of instruments are equipped with demodulators to process a wide range of modulation formats, including amplitude modulation (AM), frequency modulation (FM), amplitude-shift-keying (ASK) modulation, frequency-shift-keying (FSK) modulation, and phase modulation. The real-time spectrum analyzers provide the measurement power to capture in-phase (I) and quadrature (Q) modulation signal components like a vector signal analyzer, but with the flexibility of frequency-domain triggering.

Although both series of analyzers offer unique measurement capabilities, they can also be used in conventional spectrum-analyzer mode to "sweep" across a frequency range using resolution-bandwidth filters from 1 Hz to 10 MHz in the RSA2200A analyzers and to 15 MHz in the RSA3300A analyzers. The analyzers also offer a time-domain mode based on the use of Fast Fourier Transform (FFT) capability to display signal information as a function of time using a variety of display window types (such as Hamming, Blackman, Parzen, Welch, and Blackman-Harris windows).

Noise sidebands in the RSA2200A instruments are below –133 dBc/Hz measured 7 MHz from a 1-GHz center frequency, and below –132 measured 7 MHz from a 2-GHz center frequency. Noise sidebands in the RSA3300A instruments are below –135 dBc/Hz measured 7 MHz from either a 1- or 2-GHz center frequency. Reference levels can be set from –51 to +30 dBm with a wide range of attenuation capabilities; amplitude marker readout resolution is a precise 0.01 dB. Frequency resolution can be set from 1 MHz to 1 MHz; the carrier-frequency-measurement accuracy is ±4.01 kHz at 2 GHz.

These real-time spectrum analyzers bring new measurement capability to a wide range of applications. The analyzers are well equipped with digital-signal-processing (DSP) capabilities for detailed analysis. P&A: $22,990 and up; six weeks. **Tektronix, Inc., 14200 SW Karl Braun Dr., P.O. Box 500, M/S 55-513, Beaverton, OR 97077; (800) 426-2200, FAX: (503) 627-3678, Internet: www.tektronix.com.**

InGaP HBT Amplifier Delivers +42 dBm Output IP3

AN AMPLIFIER IC offers high IP3 and high efficiency for cellular/PCS/3G, WLL, ISM, and fixed-wireless applications from 400 to 2500 MHz. Packaged in an industry standard SOT89, the HMC454ST89 is a Form/Fit/Function alternative to competitor SOT89 amps. Utilizing a minimum of external components and operating from a single +5-V, 150-mA supply, the HMC454ST89 provides an output IP3 of +40 dBm at 900 MHz and +42 dBm at 2000 MHz. This device delivers 18 dB gain and +24 dBm P1dB from 800 to 1000 MHz, while offering 13 dB gain and +27 dBm P1dB from 1800 to 2200 MHz. The high output IP3 and PAE coupled with low VSWR makes the HMC454ST89 a suitable driver for cellular/PCS/3G, WLL, ISM, and fixed wireless applications. Samples and evaluation boards are available from stock as well as volume production quantities.

Hittite Microwave Corp., 12 Elizabeth Dr., Chelmsford, MA 01824; (978) 250-3343, FAX: (978) 250-3373, Internet: www.hittite.com.

Frequency Extenders Cover 26.5 To 110 GHz

SFE SERIES OF frequency extenders combine high-performance millimeter-wave amplifiers, passive or active multipliers, and filters to extend the low frequency sweepers, such as HP 83550 B, Agilent 83751B, or Anritsu 68000 series synthesizers, to extreme clean and low-cost millimeter-wave sources. The frequency extenders cover the output frequency range of 26.5 to 110 GHz in six waveguide bands. The typical input power for these standard units are rated at +10.0 dBm while the output power of up to 20 dBm is available. The SMA (F) coaxial connector is equipped for the input and standard waveguide for the output interface. The input DC voltage is +8.0 V. The dimension of the standard products is measured as 4.20 × 6.15 × 2.68 in. (10.67 × 15.62 × 6.80 cm).

WiseWave Technologies, Inc., 4050 Spencer St., Suite E, Torrance, CA 90503; (310) 371-5833, FAX: (310) 371-6393, Internet: www.wisewave-inc.com.

Hybrid Coupler Suits 800-to-1000-MHz Applications

A 3-DB HYBRID coupler is suitable for 800-to-1000-MHz applications. The component offers very low loss and matches the coefficient of thermal expansion (CTE) of typical power-amplifier (PA) PCBs such as FR4, G-10, Rogers 4003/4350, and Taconic RF-35 substrates, for increased durability in the field. Key specifications include: frequency of 800 to 1000 MHz; insertion loss of 0.30 dB max.; and power handling of 115 W max. The coupler measures 0.354 × 0.275 × 0.11 in. (9 × 7 × 2.8 mm). Samples are available within 24 hours for qualified prototype work.

Anaren, Inc., 6635 Kirkville Rd., East Syracuse, NY 13057; (800) 544-2414, (315) 432-8909, FAX: (315) 432-9121, Internet: www.anaren.com.

Switched Beamformer Accommodates Airborne Environments

A SWITCHED BEAMFORMER is suitable for use in airborne applications. This generic design is a digitally controlled approach that takes one input and provides four output phase states for each switch position. Operating at selected frequencies from DC to 18 GHz, these custom designs are available for 4, 8, and 16 position outputs. Units are achieved by employing multilayer construction through the use of coax, stripline, and microstrip technologies.

Technical Research and Manufacturing, Inc., 280 South River Rd., Bedford, NH 03110; (603) 627-6000, FAX: (603) 627-6025, e-mail: sales@technicalresearch.com, Internet: www.technicalresearch.com.

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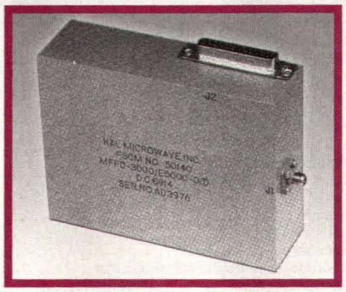
looking back



NEARLY 15 YEARS AGO, a unique modulator filter frequency discriminator (MFFD) developed by K & L Microwave (Salisbury, MD) for electronic-warfare (EW) systems measured 1-ns-risetime pulses from 3 to 5 GHz with better than 1-MHz resolution. The discriminator blended analog, RF, and digital circuitry.

next month

Microwaves & RF March Editorial Preview

Issue Theme: Communications

News

Communications systems design involves the melding of many different technologies, including DC power, analog, RF/microwave, and high-speed digital techniques. Last month's Special Report featured a survey of one of the more important building block: RF semiconductors. This month's report will investigate how RF signals are changed into the digital realm, through high-speed digitizers. This survey of high-speed analog-to-digital converters (ADCs) will include a review of key specifications when comparing products and a complete lineup of suppliers. It will also discuss important performance parameters for RF components prior to the ADC, such as mixer and filter spurious content in a receiver chain. For a high-level look at high-speed digitizers, don't miss this Special Report.

Design Features

Digital technology plays an increasingly important role in systems that begin and end with RF signals, such as military radars and commercial cellular telephones. In the digital signal chain, finite-impulse-response (FIR) filters are the means by which narrow signal channels are processed so elegantly and efficiently. In Part 3 of an article series from The MathWorks, readers will learn more about advanced FIR filter design strategies and how to model such filters with software. The issue will also feature an overview of remote-keyless-entry (RKE) systems and how the necessary components can be fabricated with semiconductor technology. Additional articles will explore techniques for characterizing reed relays through 10 GHz and examine polarimetric radar backscattering from power lines at microwave and millimeter-wave frequencies, for the purpose of detecting power lines along the paths of low-flying aircraft.

Product Technology

March's Product Technology continues the digital communications theme with a detailed look at the industry's first NRZ-to-RZ converter that seamlessly integrates microwave and optical circuitry in a compact 20 $\times$ 20 mm multichip module (MCM). The module is well suited for handling duobinary modulation in high-speed optical communications systems operating at 10 Gb/s and beyond. Additional Product Features highlight a series of low-cost oscilloscopes that can be operated without an owner's manual, the industry's first monolithic GSM handset power amplifier based on standard silicon CMOS, a versatile transceiver integrated circuit (IC) that works for all three 802.11a/b/g WLAN systems, and a family of lowpass filters that cover 0.6 to 3.0 GHz.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from ARRA, of course!
For your "sweet tooth"...
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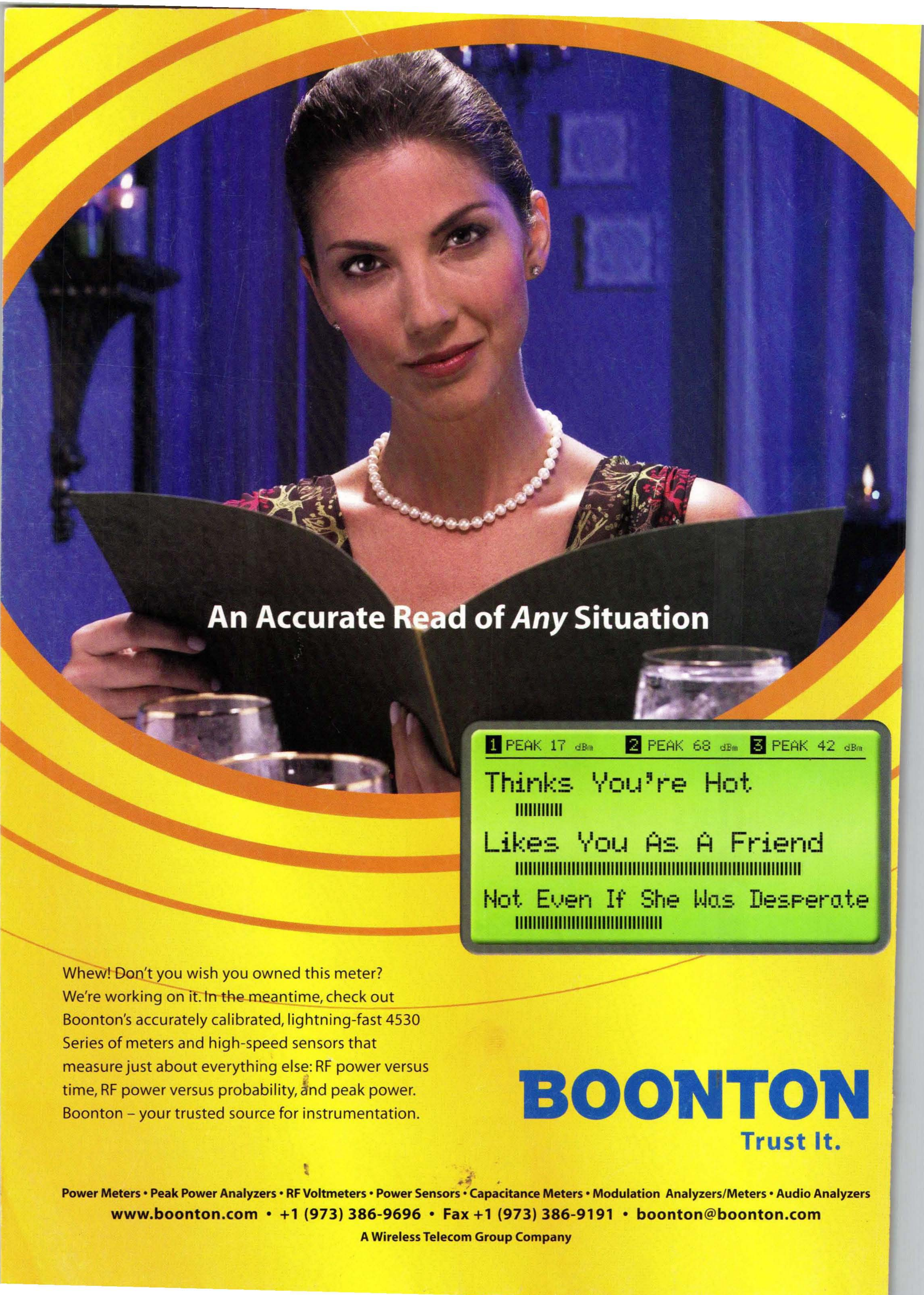
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Likes You As A Friend
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